Orchestral Gestures: Music-Theoretical Perspectives and Emotional Responses

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ABSTRACT

This dissertation employs novel interdisciplinary approaches to the study of orchestral gestures through music-theoretical investigations and perceptual listening experiments. It provides a foundation for a theory of orchestral gestures that incorporates listener experiences and considers the structural and expressive role of orchestration—a topic that is currently underdeveloped in music research.

In the first music-theoretical investigation, the development of the orchestral crescendo and other types of orchestral shaping were explored through a historical discussion of orchestral effects and textures. As a starting point for inquiry, I proposed a typology of orchestral gestures defined by changes in instrumentation based on the time course (gradual or sudden changes) and direction (additive or reductive changes). The four types relate to the descriptions in the literature of an orchestral crescendo (gradual addition), the reverse process (gradual reduction), and timbral contrasts including a rapid switch to tutti forces (sudden addition) and the drop-off to a contrast choir or soloist (sudden reduction). The conceptualization of orchestral shaping as a type of musical gesture, rather than as an effect or technique, captures its goal-directed sense of motion and expressive agency as a carrier of emotional force.

As a counterpart to the theoretical work, an exploratory perceptual experiment investigated listeners' responses to orchestral gestures. The results revealed that the response profiles differ for the four types, including a lingering effect of high emotional intensity for the gradual and sudden reduction gestures. I developed a new type of graphical visualization that provides a synoptic view of the gesture by assembling score-based and performance-based musical features. The visualizations prove to be a crucial music-theoretical and analytical tool, assisting in examining the evolution of listeners' emotional reactions in response to changes in musical features.

In the second music-theoretical investigation, the prevailing informal use of recomposition was developed into a hypothesis-testing method, which can also be used to explore the role of orchestration. In a case study, recompositions were created to examine specific structural and orchestral features of the sudden reduction gesture type. The method was employed on a large-scale level to test a hypothesis related to the connection between emotional valence and timbral brightness. Expert reorchestrations of orchestral gestures were created to study the effects of independently modifying instrumentation to adjust the relative brightness. Using the Digital Orchestra Simulator (DOSim), realistic acoustical renderings preserved performance timings and dynamic variations across the original excerpts and their reorchestrations.

In the accompanying listening experiment, subjective (arousal and valence responses) and objective (biosensor) measures were recorded continuously while participants listened to original and reorchestrated versions. Activity analysis, a new type of analytical approach, was employed to investigate response coordination and areas of high activity across the original, bright, and dark versions. Whereas the arousal measures were mainly invariant to changes in orchestration, the valence measures differed for brightened and darkened versions, although not always in the predicted direction. This research indicates that the brightness of the orchestration leading up to an expressive event dramatically shapes the resulting experience.

RÉSUMÉ

En s’appuyant sur une approche pluridisciplinaire innovante, cette thèse aborde le problème des gestes orchestraux à travers des investigations basées sur la théorie de la musique et des expériences perceptives. Ces travaux définissent les bases d’une théorie des gestes orchestraux intégrant l’expérience de l’auditeur tout en considérant le rôle structurant et expressif de l’orchestration, sujet encore très peu développé dans le contexte de la recherche musicale.

Au cours d’une première étude théorique, le développement des crescendos et d’autres types de d’arrangements orchestraux a été abordé dans une discussion sur l’histoire des textures et des effets orchestraux. Comme point de départ, une typologie des gestes orchestraux a été proposée. Elle est caractérisée par les changements dans l’instrumentation basés sur l’évolution temporelle (graduelle ou soudaine) et sur la direction (changements additifs ou réducteurs). Les quatre types de gestes définis font ainsi référence à des descriptions issues de la littérature sur les crescendos orchestraux (augmentation graduelle), les decrescendos (diminution graduelle), et les contrastes de timbre incluant soit un changement rapide vers le mode tutti (addition soudaine), soit au contraire la diminution vers un chœur ou un soliste (réduction soudaine). Ainsi, la conceptualisation de l’arrangement orchestral comme un type de geste musical plutôt qu’un effet ou une technique intègre à la fois son intention dirigée vers le sens du mouvement et son caractère expressif vecteur d’émotions.

En contrepartie du travail théorique précédent, une expérience exploratoire a étudié les réponses des auditeurs aux gestes orchestraux. Les résultats ont mis en évidence que les profils de réponses des auditeurs diffèrent en fonction des quatre types de gestes, incluant en particulier un effet persistant d’intensité émotionnelle élevée pour les gestes en réduction graduelle et soudaine Un nouveau type de visualisation graphique permettant une vision synoptique des gestes en combinant des caractéristiques issues des partitions et des performances musicales a également été développé. Ces visualisations se sont révélées être un outil analytique et théorique crucial permettant d’évaluer l’évolution des réponses émotionnelles en fonction des changements musicaux.

Dans la seconde étude théorique, l’utilisation informelle de la recomposition a été développée pour un test d’hypothèse, pouvant également être utilisée pour explorer le rôle de l’orchestration. Au cours d’une étude de cas, des recompositions ont été créées afin d’étudier l’influence des caractéristiques structurelles et orchestrales spécifiques dans le cas des réductions soudaines. Cette méthode a ensuite été utilisée à plus grande échelle dans le but d’évaluer une hypothèse sur les relations entre la valence émotionnelle et la brillance sonore. Des réorchestrations expertes de gestes orchestraux ont été créées afin d’étudier les effets indépendants d’une modification de l’instrumentation pour l’ajustement relatif de la brillance. Afin de garder un rendu sonore réaliste préservant aussi bien le tempo que les variations dynamiques entre les extraits originaux et leurs réorchestrations, le simulateur d’orchestre numérique DOSim (Digital Orchestra Simulator) a été utilisé.

Dans l’expérience perceptive accompagnant cette seconde étude théorique, des mesures subjectives (réponses d’éveil et de valence) et objectives (biocapteurs) ont été enregistrées continûment pendant que les sujets écoutaient les versions originales et réorchestrées. Un nouveau type d’approche analytique, l’analyse d’activité, a été utilisée pour évaluer la coordination des réponses et les zones de haute activité entre versions originale, brillante, et sombre. Alors que les mesures d’éveil sont restées globalement invariantes aux changements d’orchestration, les mesures de valences se sont avérées différentes entre les versions brillante et sombre, bien qu'elles ne différaient pas toujours dans la direction attendue initialement. Cette étude met donc en évidence que la brillance de l’orchestration conduisant à un évènement expressif sculpte de façon dramatique l’expérience perceptive résultante.

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CHAPTER 1

INTRODUCTION

> [T]his growing interest in emotion may reflect an increasing awareness that a central question of music psychology—how people experience music—cannot be answered without reference to the role of emotions (Sloboda and Juslin 2010, 81).

Music's connection to emotions has fascinated scholars and listeners for centuries, but has only occupied a central position in music psychology in the last two decades.[1] Despite this growing area of empirical study, there continues to be a disconnect with the field of music theory. In music and emotion research, musical analyses that attempt to connect listeners' responses with specific musical features rarely examine details beyond the immediate musical context (Gomez and Danuser 2007; Juslin and Västfjäll 2008). Traditional music theories, although they may consider the development of musical events temporally, rarely address how listeners experience musical materials as they unfold in time. Despite the challenges related to the goals and terminology of humanistic and scientific approaches, a critical need exists for interdisciplinary collaboration (Juslin and Sloboda 2010b). There is a potential for music theory and psychology to contribute to the understanding of the phenomenology of the musical experience that could not be addressed without the confluence of disciplines.

Recent empirical studies indicate that changes in instrumental texture and timbre induce strong emotional responses in listeners (Guhn, Hamm, and Zentner 2007; Panksepp 1995; Sloboda 1991). However, orchestration theory, which has not attained the depth or precision compared to other musical fields, does not provide a taxonomy or conceptual framework related to these phenomena, resulting in a limited understanding of their function and perception (Boulez 1987; Sandell 1995; Slawson 1985). This dissertation benefits from a reciprocal exchange between the

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[1] See historical discussion in Juslin and Sloboda (2010a).

fields of music theory and experimental psychology, specifically through perceptual testing of music-theoretical hypotheses related to orchestration and through the use of music-theoretical analyses to provide insight into emotional responses to music. In this introductory chapter, I provide a literature review on timbre and orchestration, as well as music and emotion, in order to contextualize the motivations behind the research in the dissertation, the methodologies employed for music-theoretical and experimental research, and the analytical tools developed in this vein.

REVIEW OF RESEARCH ON TIMBRE AND ORCHESTRATION

Orchestration theory and analysis

In comparison to the history of Western music, the study of orchestration is relatively recent. Berlioz's *A Treatise of Modern Instrumentation and Orchestration*, is regarded as the birth of study on the subject, placing the process of crafting instrumental combinations on par with the study of other musical parameters such as melody and harmony (MacDonald [1855] 2002). Despite advancements in the 19th and 20th century, such as Schoenberg's concept of *Klangfarbenmelodie* and new possibilities of timbre as a parameter in serial compositions, the study of orchestration continues to lag behind other areas of music research. There are a number of factors responsible, including the manner in which traditional orchestration practices continue to be discussed and taught. The theory behind orchestration is implicit, with expert knowledge of the art gained through experience. Orchestration treatises cover mainly what could be considered "instrumentation," with practical considerations, such as individual instrument ranges, tone qualities, doublings and common uses, intermixed with short excerpts by the masters to be studied and emulated.[2] Any kernels of what could be considered orchestration theory must be gleaned from passages providing technical advice, based on tried-and-true conventions. Most observations about orchestration in music-

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[2] Modern treatises include: Adler (2002), Kennan and Grantham (2002), Piston (1955), and Read (1979).

theoretical scholarship serve only a supportive function within the context of other analytical observations.

In addition to the lack of theory, there are very few analytical methods or tools developed to study orchestration. In *New Images of Musical Sound,* Cogan (1984) advocated for an analytical approach using a spectrogram, a visual representation of the frequency spectrum, with the x-axis representing time, the y-axis representing frequency (pitch), and the colour or shading representing amplitude. Spectrograms allow for qualitative visual analyses of spectral and temporal sound features, which are implicated in timbre perception (discussed further below). Spectrographic analysis is especially attractive for examining music for which a score is not available or the primary object of study is a recording, such as oral traditions, popular music, and electroacoustic music (McAdams, Depalle, and Clarke 2004).

Analytical approaches using spectrograms have been criticized, however, for the tenuous connection between what is visible on the graphs and what is audible in reality. Many features, such as vowel formant structure, are not legible on the spectrum plots due to obfuscation by other sound sources (Sandell 1990). The reverse is also true: prominent features on the spectrogram are not always perceptually salient. As a result, spectrographs make a "clunky middleman" between the visual data and the phenomenological perception of timbral characteristics (Blake 2012). Even with the development of new technologies to analyze timbre, there is still no clear method that incorporates an interdisciplinary approach (Zattra 2005). Generalized principles of orchestration grounded in music perception and cognition research, along with specialized analytical tools, would benefit composers and theorists alike.

Orchestration and perceptual principles

Within the field of music perception, there has been greater headway in research on musical timbre. Stephen McAdams's definition of timbre succinctly problematizes the concept and the inherent difficulties in its study:

> Timbre is a misleadingly simple and exceedingly vague word encompassing a very complex set of auditory attributes, as well as a plethora of intricate psychological and musical issues. It covers many parameters of perception that are not accounted for by pitch, loudness, spatial position, duration, or even by various environmental characteristics such as room reverberation. This leaves myriad possibilities, some of which have been explored during the past 40 years or so (McAdams 2013, 35).

Recent research has attempted to link results from perceptual experimentation with aspects of orchestration practice. Studies on the acoustical correlates of perceptual dimensions of timbre have found a robust connection between brightness and spectral centroid, which corresponds to the center of gravity of the relative weights of the frequencies present (McAdams 2013). Instruments with more energy in the upper harmonics will have a brighter or more nasal sound (e.g., oboe) compared to instruments with more energy in the lower partials with a darker tone (e.g., trombone) (Schubert and Wolfe 2006; McAdams 2013). Sandell (1995) investigated the acoustical attributes of instruments involved in attaining blend—the perceptual fusion of instrument sounds that provides the illusion that they originated from a single sound source. Based on perceptual experiments of blend ratings, he found that brighter instruments blended worse than darker instruments and pairs of instruments with maximally distant spectral centroids blended worse than pairs with closer centroids. Additionally, the similarity in the attack characteristics and the similarity in changes in loudness over time, both timbral attributes, contributed the variance in blend ratings. In a similar study, spectral and temporal similarity contributed to higher blend ratings for wind instrument combinations (Kendall and Carterette 1993). These results have implications for orchestration theory given that the acoustical properties of instrument timbres could be used to understand orchestration blend pairings and predict future choices.

The research on blend demonstrates timbre's involvement with auditory grouping at the level of musical events. Timbre is also involved in auditory stream integration—the perceptual connection of events based on sequential grouping cues (McAdams and Bregman 1979; McAdams 2013). The auditory system expects a sequence of events produced by a single sound source to behave similarly in terms of its spectral content (pitch and timbre), intensity (sound level), and spatial position. Therefore, continuities in these cues would likely cause the integration of the events into a single stream, whereas discontinuities potentially signal other sound sources, causing the segregation of the events into different streams. Studies in this area have shown that spectral (e.g., spectral centroid) and temporal (e.g., attack time) timbral attributes are implicated in stream segregation (Singh and Bregman 1997; Iverson 1995). Bey and McAdams (2003) interleaved a target melody with a distractor melody and asked participants to identify whether a subsequently presented test melody was present in the mixture. Participants' accuracy increased as a function of the timbral dissimilarity between the target and distractor instruments. McAdams (2013) suggests that the theory of auditory stream formation related to the acoustical properties of timbre has important implications for understanding orchestration practice, as the choice of instruments may promote or prevent stream segregation of melodies.

In addition to concurrent (blend) and sequential (melody segregation) grouping processes, timbre also promotes segmental grouping, a process by which listeners "chunk" musical streams into units such as phrases and themes. In *A Generative Theory of Tonal Music*, Lerdahl and Jackendoff (1983) proposed segmental grouping rules based on principles of proximity and similarity from Gestalt psychology. Deliège (1987; 1989) experimentally tested these grouping rules and found that one of the most frequently used segmental grouping principles involved discontinuities in timbre.

More research is needed to investigate how orchestration interacts with other musical parameters to shape musical form and musical expression.

Influence of orchestration on the listening experience

During the past two decades, several empirical studies have investigated the features in music that give rise to musical emotions. In addition to musical parameters related to harmony and melodic contour, changes in instrumental texture and timbre have also been found to elicit emotional responses. In Sloboda's (1991) questionnaire study, he analyzed the musical passages that participants identified as eliciting emotions with specific physical reactions. In addition to specific harmonic or melodic patterns, a sudden dynamic or textural change elicited tears, increase of heart rate and chills—a strong emotional response involving goose bumps, shivers, or tingles down the spine.

In Panksepp's (1995) group-listening studies, participants were asked to raise their hand at the moment they experienced a chill. Peaks in the number of experienced chills corresponded to "the most intense and dramatic crescendos" (Panksepp 1995, 169–170). He also proposed that the same emotional feeling could be achieved through "the piercing simplicity of certain solo pieces that emerge from a richer orchestral background" in combination with a mood of nostalgic sadness (Panksepp 1995, 193). In other words, goal-directed crescendos and a reduction of instrumental forces (e.g., a solo instrument emerging out of the orchestra) have the capability of producing strong emotional responses.

Guhn, Hamm, and Zentner (2007) collected physiological measures and asked participants to push a button to indicate when they experienced chills. Their musical analyses of passages that elicited chill responses revealed similar musical characteristics: a slow tempo, a sudden or gradual volume increase from *piano* to *forte*, an expansion of the frequency range in the high or low register, harmonic progressions that deviate from an expected pattern, and the alternation of a solo instrument and the orchestra.

The studies discussed above consistently cite changes in texture and timbre as an important musical feature involved in eliciting musical emotions. Musical texture can refer informally to the density of the number of instrumental parts (i.e., thin vs. thick texture). In this context, musical texture involves the displacement of the parts in terms of its *ambitus* (range or spread) and the number of instruments involved. Both the abrupt switch between full forces to a thin texture (or soloist) and the gradual buildup of instrumental textures to create a dynamic and textural climax were reported as being highly emotionally evocative. These types of large-scale changes in orchestration are not addressed sufficiently in music theory or orchestration theory. As Guhn and others have indicated, musical features combine to produce climactic effects; therefore, the interaction of musical parameters with musical texture is an important but underdeveloped area of study.

Connection between spectral centroid and emotional valence

As a multidimensional phenomenon, timbre is a complex musical parameter. One perceptually relevant dimension is the connection between spectral centroid and the perceived brightness of a sound (McAdams 2013). In relation to orchestration, timbral brightness has been found to be connected to an instrument's ability to blend with other instruments (discussed above) and to its affective character.

Orchestration treatises attribute associations between the emotional qualities of instruments (or groups of instruments) and their perceived brightness or darkness. I interpret these connections within the dimensional model of emotion, in which emotions are understood based on their location along dimensions of arousal (low to high) and valence (negative to positive), based on Russell's

(1980) circumplex model (described further below). Common associations include brightness and positively valenced emotions, as well as darkness and negatively valenced emotions, such as the bright and heroic register of the French horn (Adler 2002, 316), and the somber, dark, and sonorous harp in the low register (Adler 2002, 92). Rather than a strict dichotomy, an interaction with arousal is also evident; piercing, bright timbres are also connected to anger (i.e., high arousal and negative valence) (Kennan and Grantham 2002, 90), and dark or warm timbres are associated with sonorous and mellow affects (i.e., low arousal and positive valence) (Adler 2002, 92).

Empirical evidence also points to a similar association between instrumental timbre and affect. In particular, several studies have shown evidence of spectral centroid differences as a factor in emotional vocal expression and music performance (Juslin and Timmers 2010; Juslin and Laukka 2003). Happiness and anger (both high arousal emotions) were associated with bright or sharp instrumental timbres, whereas sadness and tenderness (both low arousal emotions) were associated with dull or soft timbres (Juslin 2000; Gabrielsson and Juslin 1996; Eerola, Ferrer, and Alluri 2012). Less of a clear relationship exists between emotional valence and the time varying spectral centroid of the orchestra (Schubert 2004). A study design that systematically manipulates spectral centroid would assist in understanding its connection to emotional experiences.

My dissertation points a way towards filling a gap in the research. I investigate large-scale orchestral shaping to explain textural and timbral changes that give rise to strong emotional responses through examination of historical accounts of orchestral effects and orchestration treatises. Additionally, I investigate the effect of instrumentation adjustments to brighten or darken (i.e., increase or decrease the spectral centroid) while controlling for other musical parameters. The music-theoretical investigations incorporate a listener-oriented perspective through accompanying listening experiments. The following section provides a literature review of music and emotion research, outlining the major issues in the field and methods to measure emotional responses to music.

MUSIC AND EMOTION LITERATURE REVIEW

Introduction and definition of emotion

Within the growing interdisciplinary field of music and emotion research, the literature presents an inconclusive picture of listeners' responses to music, with conflicting views on many fundamental concepts in the field (Juslin and Västfjäll 2008; Eerola and Vuoskoski 2013). Terminological confusion continues to be a concern; terms such as affect, emotion, feeling, and mood are used inconsistently and sometimes interchangeably, which has caused issues with generalization and exchange across studies (Juslin and Sloboda 2010a). In the recent *Handbook of Music and Emotion,* editors Juslin and Sloboda (2010a) propose the following definition of emotion:

> This term is used to refer to a quite brief but intense affective reaction that usually involves a number of sub-components—subjective feeling, physiological arousal, expression, action tendency, and regulation—that are more or less 'synchronized'. Emotions focus on specific 'objects' and last minutes to a few hours (e.g. happiness, sadness) (10).

One of the major disputes concerns whether music truly induces emotions or only expresses emotional qualities.[3] So-called cognitivists argue that listeners are able to recognize and interpret emotions that music expresses, but genuine emotions are not evoked by the music itself (Kivy 2001; Konecni 2008). The cognitivist position asserts that "garden variety" emotions, such as happiness and sadness, require real-life consequences and adaptive functions that are not found in music. In addition, cognitivists maintain that emotions require a cognitive appraisal of a target, which does not exist in music. On the other side of the argument, emotivists claim that music is capable of arousing deep emotions in listeners (Sloboda and Juslin 2001; Krumhansl 1997; Lundqvist et al. 2009). Juslin,

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[3] A useful table summarizes the methodological approaches and emotional models for perceived and felt emotions in music and emotion research in Zentner and Eerola (2010, 196)

Liljeström, Västfjäll, and Lundqvist (2010) have proposed several underlying mechanisms, in addition to cognitive appraisal, that explain how music is able to evoke emotions in listeners (discussed further below). The focus of research in recent years has shifted toward felt emotions, and the majority of research supports the emotivist position.[4]

The distinction between emotion induction and emotion perception continues to be a methodological problem (Gabrielsson 2002; Eerola and Vuoskoski 2013). The connection between recognized and felt emotion is not always straightforward (Gabrielsson 2002). The generalizability across studies becomes an issue if researchers do not observe the distinction between perception and induction of emotions and if participants conflate perceived qualities as felt emotions (Sloboda and Juslin 2010).

Emotion models

In regards to theoretical models of emotion, the two most common are the discrete and dimensional models, which are used in the majority of past studies (Eerola and Vuoskoski 2013). The discrete or categorical model asserts that emotions are experienced as distinct categories derived from a limited number of universal and innate basic emotions, which typically include fear, anger, disgust, sadness, and happiness (Ekman 1999). Many studies have modified the subset of emotions to feature more musically relevant categories, replacing less pertinant emotions such as fear and disgust with other more musically related ones such as tenderness and peacefulness (Eerola and Vuoskoski 2013). Criticisms of the categorical model include the inadequacy of a few primary emotions to represent the wide range of emotional responses to music and the often arbitrary choice of subsets used by experimenters (Scherer 2004; Zentner, Grandjean, and Scherer 2008).

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[4] Examples of research in support of the emotivist position include: Gabrielsson (2010), Whaley, Sloboda, and Gabrielsson (2009), Zentner, Grandjean, and Scherer (2008).

The dimensional approach has been heavily influenced by Russell's (1980) circumplex model, in which emotions are understood as involving varying degrees of activity along two indpendent neurophysiological systems related to valence (pleasure-displeasure) and arousal (activation-deactivation). In recent studies, the bipolar dimensions are often redefined as negative to positive valence and low to high arousal (Zentner and Eerola 2010; Schubert 2004; Egermann et al. 2015). The model has been criticized for the lack of differentiation between emotions that are close in two-dimensional space (e.g., anger and fear, both emotions with negative valence and high arousal) and for its inability to account for all the variance in emotional responses (Eerola and Vuoskoski 2010). Additionally, several studies have found that music listeners feel mixed emotions, which cannot be plotted onto a two-dimensional space (Eerola and Vuoskoski 2013). A three-dimensional model—pleasure-displeasure, awake-tired, and tension-relaxation—has also been proposed (Schimmack and Grob 2000), but has been largely been ignored in the emotion literature. A recent study found that three dimensions could be reduced to two without significantly reducing the extent to which the model represents the data (Eerola and Vuoskoski 2010). Researchers must be aware of the limitations of the emotion models when collecting participant responses (addressed further below).

Types of emotional responses to music

Despite disagreements among researchers regarding emotion models, there is greater consensus on the characteristics and components of emotional responses, which can include subjective feelings, psychophysiological reactions (e.g., changes in heart rate and respiration), brain activation (i.e., regions of the brain related to emotions respond during music listening), behavioral expression (e.g., tears, laughter, eyebrow furrowing), action tendencies (i.e., overt motion or urges to move), and emotion regulation.[5] Various methods of measuring emotional responses have been used to tackle the different components of these responses and will be discussed in the measurement section.

Psychophysiological activity involves both physiological changes (e.g., heart rate, blood pressure) and overt, expressive behaviours such as crying, facial expressions, and body movements (Hodges 2010). In his summary of the current research in the field, Hodges (2010) notes that processes associated with the autonomic nervous system (ANS) and the somatic nervous system are intimately involved with emotional responses. Responsible for maintaining homeostasis, the ANS regulates organs of the cardiovascular, gastrointestinal, electrodermal, respiratory, endocrine, and exocrine systems. The sympathetic division of the ANS prepares the body for fight or flight situations by energizing the body through increasing heart rate, blood pressure, and tension in muscles, as well as the secretion of adrenalin and neurotransmitters. The parasympathetic division works in parallel to conserve energy and returns the body to a state of rest. The somatic nervous system controls skeletal muscles, including tension in facial muscles related to smiling and frowning.

Music and emotion researchers have attempted to find connections between subjective emotional responses and concomitant changes in psychophysiology. The componential approach to emotion asserts that emotional responses consist of coordinated changes in several components: experiential (i.e., self-reported feelings), autonomic (i.e., physiological changes) and behavioural (i.e., observable phenomena such as action tendencies and facial expressions) (Scherer 2004; Sloboda and Juslin 2010).

One growing area of study is the chill response or *frisson*, which involves goose bumps, shivers, or tingles down the spine. The appeal of this area relates to the correspondence between a specific subjective emotional experience and specific psychophysiological arousal responses

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[5] See the summary table in Juslin and Västfjäll (2008).

(increases in skin conductance and heart rate) (Guhn, Hamm, and Zentner 2007; Craig 2005; Rickard 2004). Greater brain activity has been found in centers related to reward, emotion, and arousal during chills induced by music listening (Blood and Zatorre 2001). Additionally, dopamine release was found during anticipation of and experience of chills in the reward systems of the brain (Salimpoor et al. 2011). Due to the complexity of the chill phenomenon during music listening, there are some disadvantages in this field of research: chill experiences are rare emotional events and are not reported by all listeners.

Another promising area of study involves the broader response category of strong experiences with music, which are powerful, salient, and memorable experiences (Whaley, Sloboda, and Gabrielsson 2009; Gabrielsson 2010). Typical elements include physical reactions (e.g., chills, tears, and changes in heart rate), perceptions (e.g., intensified/multimodal perception), cognitions (e.g., loss of control), feelings/emotions (e.g., positive, negative or mixed emotions), as well as existential/ transcendental (e.g., reflections on life) and personal/social aspects (e.g., feelings of hope and power). These experiences have been studied extensively through retrospective self-reports. In order to investigate the temporal aspects of strong emotional experiences, the ideal approach involves converging methods to collect both subjective measures of self-reporting (concurrent and retrospective) and objective physiological measurement.

How does music evoke emotions in listeners?

Over the past decade, researchers have acknowledged that there is likely more than one mechanism involved in evoking emotions in music listening (Juslin and Sloboda 2010a; Juslin and Västfjäll 2008; Scherer 2004). Juslin and Västfjäll (2008), and more recently Juslin, Liljeström, Västfjäll, and Lundqvist (2010), proposed an integrated framework of underlying psychological mechanisms for emotion induction in music. The seven mechanisms (brain stem reflexes, rhythmic entrainment, evaluative conditioning, emotional contagion, visual imagery, episodic memory, and musical expectancy) each incorporate a distinct type of information processing that may be simple or complex, and conscious or unconsciously driven; yet, all of the mechanisms are activated by music as the object.

Brain stem reflexes involve a process in which one or more fundamental acoustical characteristics of the music are assessed by the brain stem to signal a potentially important and urgent event, thereby increasing arousal in the listener. Rhythmic entrainment refers to the manner in which musical rhythm interacts with internal body rhythms causing the listener's heart rate to synchronize to a common periodicity, thereby increasing the arousal in the listener and transfering a subjective feeling through proprioceptive feedback. Evaluative conditioning involves inducing an emotion due to repeated pairing of a musical stimulus with other positive or negative stimuli. Emotional contagion refers to the process in which the listener internally mimics the emotion expressed in the music through peripheral feedback or a relevant emotional representation in brain. For visual imagery, a listener conjures visual images while listening to music and the interaction between the images and the music evokes an emotion. Episodic memory involves emotion induction due to a personal memory of a particular emotional event, and has been referred to as the "Darling, they're playing our song" phenomenon. Musical expectancy refers to a process whereby an emotion is evoked due to a specific musical feature that violates, delays, or confirms the listener's musical expectations, which can lead to reactions such as surprise. Juslin et al. (2010) suggest that listeners may activate different mechanisms to the same musical stimulus, which may explain why diverse emotional responses may be elicited by a single piece.

It is important for researchers to consider the underlying mechanisms when studying emotional responses to music. For example, researchers may need to avoid well-known excerpts in order to minimize the possibility that participants' responses are related to personal or external associations (i.e., episodic memory and evaluative conditioning mechanisms).

Measuring and analyzing emotional responses

The majority of music and emotion studies collect data through self-report methods, which involve retrospective, subjective judgments by listeners (e.g., adjective checklists, rating scales, questionnaires, free descriptions, and journal entries) (Eerola and Vuoskoski 2013). The limitations of these approaches are rarely questioned, but pose significant challenges. In addition to the difficultly verbalizing ineffable experiences, an imperfect relationship exists between the experience of emotions and their description (Sloboda and Juslin 2001). Additionally, retrospective self-reports are problematic due to the limited temporal information. Even with these shortcomings, strong emotional experiences may not be fully understood without subjective accounts (Gabrielsson 2010).

Recent technological advances have allowed researchers to track responses to music over time, including aesthetic judgments, perceived tension, emotional arousal and valence dimensions, and emotional force. A number of continuous rating devices have been developed, such as spring-loaded tongs (Nielsen 1983), the continuous response digital interface (CRDI) dial (Madsen and Fredrickson 1993), a virtual slider or emotion space manipulated by a mouse (Farbood 2012; Schubert 2004), and a handheld mechanical slider box (McAdams et al. 2004). There has been some criticism about the cognitive load required to concentrate on the ongoing fluctuations in emotional experiences (Eerola and Vuoskoski 2013). However, the continuous rating method has been used successfully; the task is intuitive and does not require musical expertise (Schubert 2004).

In contrast to subjective measures, so-called objective measures have been used to measure psychophysiological mechanisms while listening to music. The most common include heart rate, respiration rate, skin conductance, muscular tension, and facial expressions. Heart rate or pulse rate is calculated based on the number of beats per minute collected by an electrocardiogram, which uses electrodes to collect the electrical activity of the heart, or a photoplethysmograph, an infrared light source to record the phasic changes in blood volume in capillaries with each heartbeat. Increases in heart rate have been found in relation to both arousing and calming music (Hodges 2010). Respiration rate, the number of breaths per minute, is measured by a stretch sensor or plethysmograph belt recording volume changes of the chest. Increases and decreases in respiration rate, as well as entrainment with musical rhythm, have been reported in relation to music (Hodges 2010). Electrodermal activity (EDA) measures the changes in electrical conductance of the skin, which varies based on the production of sweat by the eccrine sweat glands on the palms and fingers, and is associated with physiological arousal and attention to a stimulus. Several studies have reported significant changes in skin conductance response while listening to music (Hodges 2010), with greater responses to music with higher arousal (Khalfa et al. 2002). Surface electromyography (EMG) is a noninvasive measure of muscular activity, using electrodes to detect firings of muscle groups. Cacioppo, Bush, and Tassinary (1992) found evidence that facial muscle activity, even when too subtle to produce a perceptive expression, is modulated by affective and communicative processes. Activity of the *zygomaticus major* muscle occurs when the cheek muscles are tightened during smiling, whereas the *corrugator supercilii* muscle is responsible for lowering and contraction of the eyebrows during frowning or scowling (Tassinary, Cacioppo, and Vanman 2007). The zygomaticus and corrugator have been found to be active during music with positive and negative affect, respectively (Hodges 2010).

Continuous response data pose considerable methodological issues, particularly in terms of statistical analyses. One major obstacle is that the assumptions of independent samples and normal distribution of data are violated with responses collected over time. Another concern is that the participants do not respond immediately to a stimulus, and this response delay must be factored into the analysis. To address these issues, several different analytical approaches have been developed. Time series analysis has been used for multivariate analyses of correlations between acoustical features and perceptual ratings (Dean and Bailes 2010). Schubert (2004) proposed a quantitative modeling procedure, which involves the ordinary least squares approach of linear regression and takes into account response delay and serial correlation. Functional data analysis has been used by McAdams et al. (2004) to model data as functions of time to investigate the role of musical structure and context on emotional force and the recognition of musical materials. These approaches still often rely on means or median responses as a measure of central tendency. More recently, Upham and McAdams (2014) have developed "activity analysis," a novel technique that investigates coordination in audience responses and pinpoints various moments where this activity converges or diverges in a group of listeners.

Moderating factors

Another reason for the difficulty in studying emotional responses to music is the role of individual differences in listeners. A multitude of factors, including personality traits, moods, preferences, and familiarity with musical stimuli, can influence an individual's emotional experience (Vuoskoski 2012). Research has shown that emotional responses to music result from a complex interaction with the listener and the context, and depend on the intentions of the listener (Sloboda and Juslin 2010). Therefore, it is important to control for many of these factors as much as possible in an experimental design.

Familiarity plays a role in modulating listeners' emotional responses to music and has been found to increase emotional intensity (Ali and Peynirciolu 2010). There is also a well-established interaction between familiarity and preference (i.e., liking a piece of music), with an exposure effect reported frequently in response to music (Hunter and Schellenberg 2010; Szpunar, Schellenberg, and

Pliner 2004). Due to the connection between familiarity, preference, and emotional intensity, a listener's previous exposure to a musical stimulus can act as a confounding variable when attempting to determine the musical features responsible for emotional response (Schubert 2007).

Past research is inconclusive regarding the role of training on emotional responses to music. In comparison to trained musicians, nonmusicians have been found to be equally as receptive to the perceived emotional quality of musical excerpts (Bigand et al. 2005; Bigand and Poulin-Charronnat 2006). Similarly, several studies have reported that perceived tension was not greatly affected by musical expertise or familiarity with the stimulus (Fredrickson 1999; Fredrickson 1997; Krumhansl 1996). In a recent tension study, however, musicians were found to be more sensitive to changes in most musical features (e.g., harmony, dynamics, and onset frequency), with the exception that nonmusicians were more influenced by changes in pitch height (Farbood 2012). In a study on the effect of harmonic expectancy violations on brain processing of emotional stimuli, responses did not differ in amplitude between musicians and nonmusicians; however, musicians' responses were earlier, which suggests enhanced processing abilities of harmonic expectancy violations and greater sensitivity to stylistic violations (Steinbeis, Koelsch, and Sloboda 2006). These studies have been criticized for their use of undergraduate or conservatory students as experts, which may downplay the effects of extensive training (Bigand and Poulin-Charronnat 2006). In order to understand the role of expertise, experimenters should recruit participants with a clear distinction between the levels of training of musical experts and nonmusicians.

Issues in past research

One of the major issues in previous research is related to stimulus selection. In a recent survey of music and emotion studies, Eerola and Vuoskoski (2013) found that approximately one third did not report accurate details about the musical stimuli, which indicates that these findings would be difficult or impossible to replicate. Systematic manipulation of musical parameters is not a common approach in this field, as the majority of studies used researcher-selected, commercially recorded music (Eerola and Vuoskoski 2013). The reasoning behind these recordings is often unclear and seemingly arbitrary. Extensive use of famous or popular repertoire may confound the results given the connection between familiarity and emotion induction mechanisms of evaluative conditioning and episodic memories.

Previous empirical studies have found important insights into the link between music and emotion; however, the musical features are rarely considered beyond their immediate context (Gomez and Danuser 2007; Juslin and Västfjäll 2008). Previous studies that situate music within one quadrant of a two-dimensional emotion space or within a single emotional category limit the applicability of the results for music in which there are changes in emotional expression. Future work is needed to consider how the music evolves over time and to design experiments that involve systematic manipulation of musical features.

CHAPTER OUTLINES

This dissertation contains two music-theoretical investigations, both of which are accompanied by experimental testing. In an effort toward addressing the gap of research related to orchestration and music and emotion, I propose a typology related to textural/timbral changes and a hypothesis regarding the relationship between spectral centroid and emotional valence. The music-theoretical explorations are accompanied by experimental testing that investigates listeners' responses over time. I also develop two analytical tools to study orchestration and its interaction with other musical features. My approach addresses the issues and limitations in previous research by adopting a listener-oriented approach to music theory and by investigating listeners' emotional responses with consideration of the surrounding large-scale musical context. In addition to the use of commercially recorded music in the first study, the second study uses musical stimuli in which the instrumentation is manipulated while controlling for other musical features. The following paragraphs present a brief outline of the dissertation.

Chapter 2 contextualizes the development of the orchestral crescendo and other types of orchestral shaping through a historical discussion of orchestral effects and the evolution of orchestral textures. Within the framework of musical gestures, I propose a typology of *orchestral gestures* and demonstrate the application of a new visualization tool to analyze and compare gestural processes of score-based and performance-based musical features. In analyses of representative musical examples from the late-Romantic symphonic repertoire, I uncover expressive gestural meanings by investigating the coordination of musical parameters and their development over time.

Chapter 3 reports the results of an exploratory behavioural study that investigated listeners' emotional responses to musical examples featuring the four types of orchestral gestures. Musicians and nonmusicians continuously rated the intensity of their emotional responses with a force-feedback slider. They also completed questionnaires outlining their subjective experiences (e.g., familiarity, preference, and number of chills) after each excerpt. A time series regression study was used to predict changes in emotional responses by modeling changes in several musical features, including instrumental texture, spectral centroid, loudness, and tempo. A visualization tool was developed to analyze the emotional response profiles as well as the instrumentation changes and their interaction with other musical features.

Chapter 4 introduces a hypothesis-testing method of recomposition and reorchestration. The first section comprises a case study in which I demonstrate the application of the method to gain a greater understanding of orchestral gestures. In the second section, the method of reorchestration is used on a larger scale to investigate the effects of independently modifying instrumentation to adjust orchestral brightness, as measured by the spectral centroid. I outline a hypothesis regarding orchestral brightness, analyze three expert reorchestrations, and discuss the various techniques used to achieve these effects.

Chapter 5 is concerned with the connection between orchestral brightness and its effect on the valence of emotional responses. Expert reorchestrations of three orchestral gestures were created by adjusting the instrumentation to augment or diminish the global spectral centroid. The original and new versions were acoustically rendered in a realistic manner, controlling for performance timings and dynamic variations. In group-listening sessions, a converging-methods approach was used to collect both behavioural (continuous ratings of arousal and valence) and psychophysiological measures while participants listened to various versions. Activity analysis was used to investigate whether there were differences in audience coordination and response activity across the original, bright, and dark versions in relation to the hypothesis presented.

Finally, Chapter 6 summarizes the main findings presented in this study and discusses directions for future research.

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CHAPTER 2

ORCHESTRAL GESTURES

This chapter investigates the development of the orchestral crescendo and other types of orchestral shaping through a historical discussion of orchestral effects and textures. In previous music-theoretical discourse, the term "orchestral gesture" has been used informally, often as a description of an expressive device that is driven by the orchestra. Based on exploration of orchestration treatises and research on metaphorical musical gestures, I define four types of orchestral gestures based on changes in instrumental texture and explore their expressive meanings through detailed analyses.

This chapter is based on the following research article:

Goodchild, M., "Orchestral Gestures," Manuscript prepared for submission.

ABSTRACT

While there has been recent scholarly interest in the historical development of the orchestra, there continues to be a dearth of research and theories of timbre and orchestration, particularly large-scale orchestral shaping. Within the framework of musical gestures, I propose a typology of orchestral gestures based on the direction and time course of textural change(s). I also demonstrate the application of a new visualization tool to analyze score-based and performance-based musical features. This paper uncovers expressive gestural meanings through the investigation of the processes of orchestral gestures and their evolution over time. The aim is to provide a starting point for inquiry in the pursuit of a theory of orchestral gestures.

INTRODUCTION

Symphony 6, Hob.I:6 (1761), Haydn's first symphonic work for Prince Nikolaus Eszterházy, received the nickname "Le Matin" for its unmistakable depiction of a sunrise at the beginning of the first movement.[1] The effect is achieved through the coordination of dynamics, harmony, rhythmic activity, range, texture, and orchestration (Brown 2002). As shown in Example 2-1, the slow introduction begins with the first violin alone at *pianissimo* with a simple figure embellishing scale degree one. In measure 2, the second violin enters in canon a third below the first violin, thereby revealing the major tonality. Measure 3 heralds the entries of the bassoon, horns, cello, and double bass, which solidify the tonality by adding the tonic pedal point. In measure 3, the upper woodwinds have staggered entries, doubling the motion in the violins. A 7-6 suspension chain presses the music forward with a *crescendo* through subdominant and dominant harmonies over a tonic pedal, resolving to the tonic in the following measure on beat 3. Expanding the ambitus further, the bass line steps down through a secondary dominant to arrive on the goal dominant harmony at *fortissimo* in measure 5. Measures 5-6 function as a standing-on-the-dominant, emphasizing the arrival through descending arpeggios.

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[1] The sunrise feature of the symphony is often mentioned by scholars (Landon 1955; Hodgson 1976; Brown 2002; Todd 1986; Spitzer and Zaslaw 2004).

Example 2-1. Haydn, Symphony 6, Hob.1:6, "Le Matin," mm. 1-7.

The descriptive narrative helps to account for the main features that sculpt this orchestral crescendo. However, a visualization of the musical parameters allows for a more comprehensive analytical approach, revealing valuable insights into the coordination and interaction of musical features. The visualization in Figure 2-1 presents a synoptic view of the excerpt with graphical representations of the aforementioned musical parameters for visual comparison and examination. Moving from left to right, the x-axis represents the progression through the excerpt over time at every eighth-note beat. Beginning at the top of the visualization, the harmonic analysis shows the expanded tonic prolongation and the quick motion to the dominant harmony through a secondary dominant. The succession of notated dynamic changes corresponds with the harmonic rhythm, as the *crescendo* co-occurs with the motion through the subdominant and dominant harmonies. Similarly, the arrival on the dominant corresponds with the *fortissimo* dynamic. The pitch contour tracks the highest and lowest pitches at every eighth-note beat to provide an indication of the notated spread, or *ambitus,* and its evolution over time. In coordination with the tonic prolongation and soft dynamic, the ambitus remains narrow in the mid-register for the first two measures and expands rapidly and peaks with the move to *fortissimo* on the dominant harmony. Displayed as a stacked bar graph, instrumental texture represents the number of independent parts for the string, woodwind and brass sections (distinguished by colour), providing a visual analog to textural thickness.[2] Similarly, onset density counts the number of onsets or attacks in each instrumental family as a measure of rhythmic activity, thereby differentiating between sustained pitches (low onset density) and rapid figuration (high onset density). Although textural saturation is reached by the second half of measure 3, the peak of onset density does not occur until measure 5. Therefore, the sunrise intensifies through the gradual addition of instrumental parts, followed by the continued increase in rhythmic activity.

The visualization provides a crucial tool for analysis by moving beyond anecdotal or descriptive accounts of musical processes. The graphs incorporate musical features, such as orchestration, that are largely neglected in traditional music analysis. They provide a means to study in detail the compositional techniques used to sculpt and shape musical processes over time. Importantly, visualizations assist in comparing and contrasting similar effects in order to develop an understanding of common and unique procedures used by various composers.

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[2] The texture parameter is described in greater detail below and is based on Schubert (2004).

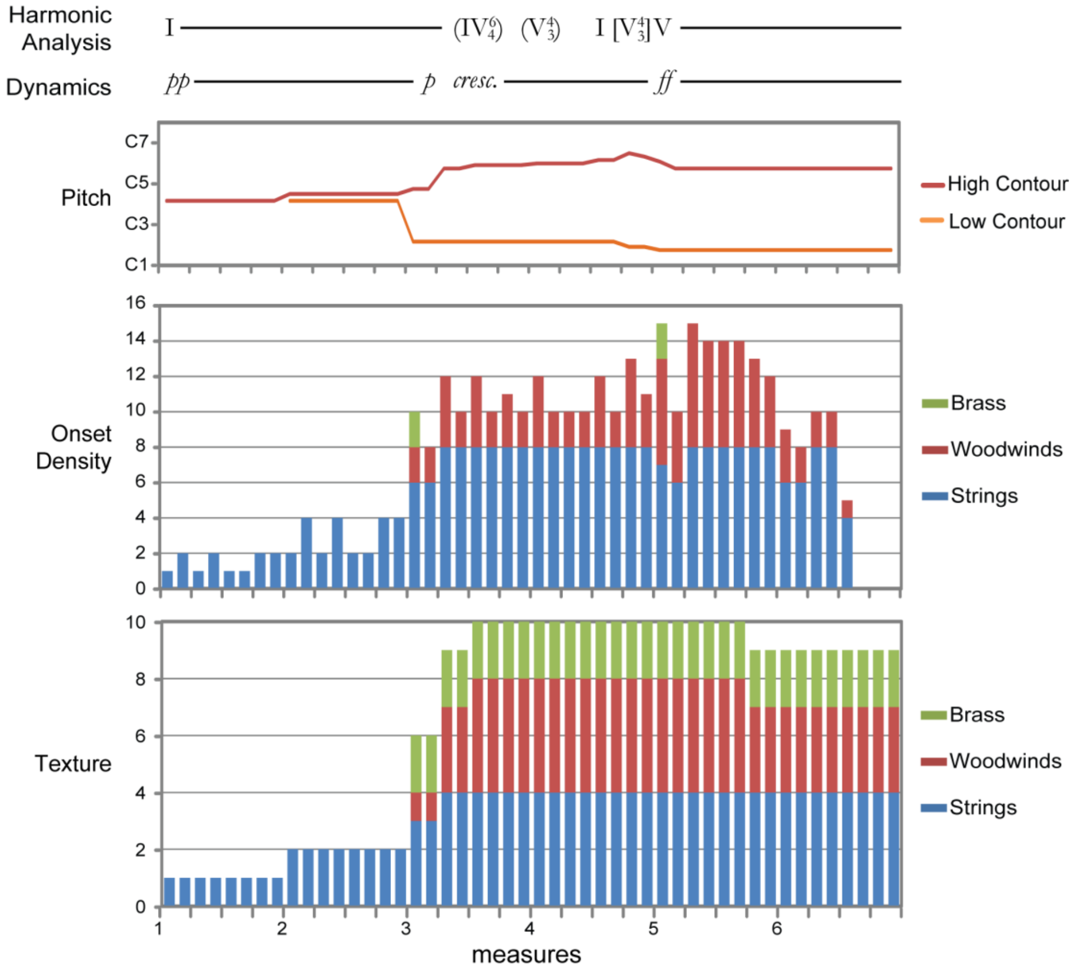

Figure 2-1. Visualization of Haydn, Symphony 6, I (mm. 1-6) with graphical representations of harmony, dynamics, pitch range, onset density, and instrumental texture.

Haydn's depiction of a sunrise was not created in a vacuum. How does this opening relate to prior uses of an orchestral crescendo as popularized by the Mannheim school? How do nineteenth-century composers expand this process to build moments of climactic force? In this study, I contextualize the development of the orchestral crescendo and other types of orchestral shaping through a historical discussion of orchestral effects and orchestral textures. Within the framework of musical gestures, I propose a typology of *orchestral gestures* and demonstrate the application of the visualization tool to analyze and compare gestural processes from the late Romantic symphonic literature. The aim of this paper is to contribute to the development of a theory of orchestral gestures.

ORCHESTRATION AND TIMBRE

Historical context

The development of the modern symphony orchestra can be explored through many narrative paths: tracing increases in its size and power, outlining technical advancements of instruments, or following the rise in status of instrumental music. R. Larry Todd (1986) frames his discussion in terms of orchestral texture: the progression from the classical ideal of texture as a structural device to the Romantic ideal of texture as an agent of expression.[3] By the middle of the eighteenth century, the standard orchestra was based on a core four-part string texture. The basic melodic and harmonic material was scored for the strings, while the winds provided support by adding a harmonic backdrop, doubling the melody, or adding short solo passages. Given these limited resources, Todd notes that composers utilized two types of textural change: contrast textures or gradual changes. To create contrasting textures, composers alternated the orchestral tutti with a solo passage. Alternatively, composers could gradually change textures by building a crescendo or diminuendo through the careful addition or removal of instruments in progressive stages. These textural changes assisted in demarcating formal structure, continuing into the late eighteenth century as the orchestra grew and was standardized.[4]

Spitzer and Zaslaw (2004) also discuss the orchestral crescendo as one of the orchestral effects developed by eighteenth-century composers. They divide effects into two categories: (1)

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[3] Todd does not explicitly define texture; however, the Glossary in the volume provides the following definition: "A combination of acoustic characteristics, including tone color, the number of parts, spacing of chords, and thickness of sonority" (Stauffer 1986, 613).

[4] See also the discussion of the use of instruments as a means to create contrasts in expressive character in baroque and early classical pieces in Weaver (1986).

effects of unity and grandeur that highlight the size and power of the orchestra, and (2) effects of variety and nuance that feature the diversity of timbres and contrasts among instruments. Given the emphasis on the strings, effects of unity and grandeur originated earlier than the effects of variety and nuance, which exploit the winds. Spitzer and Zaslaw note that orchestral effects developed from theatrical music, such as opera overtures, dramatic symphonies, accompanied recitatives, and stock arias. By the late eighteenth century, the effects lost their associations with theatrical contexts and eventually represented the splendor of the orchestra itself.

I argue that the effects outlined by Spitzer and Zaslaw also employ contrasts or gradual changes in instrumentation. The effects of variety and nuance, in particular, provide contrast through timbral changes and reduced scorings. The crescendo incorporates gradual changes over time in order to emphasize climactic or dramatic phrases. Spitzer and Zaslaw (2004) suggest that the development of orchestral effects corresponds to what became known as orchestration—"the division of a musical composition among the instruments of the orchestra for artistic effect" (439). The effects described by Spitzer and Zaslaw represent the tools and techniques that the classical composers developed into large-scale gestures in the nineteenth century.

Similarly, Emily Dolan (2013) refers to two rates of change in her discussion of Haydn's orchestration. She notes that Haydn uses instrumentation to transform the material through subtle nuances or to provide dramatic surprise through shifts in colour and texture. In his later symphonies, Haydn's trademark style of developing variation incorporates elaborate processes of continuous change in terms of orchestration. While many authors have stressed the role played by Haydn's orchestration in articulating form, Dolan argues that this notion is not sufficient to explain his compositional technique. She proposes that form, harmony, and orchestration all contribute to the effect and experience of the music.

Todd notes that once the principles of combining and contrasting string and wind groups were established, nineteenth-century composers continued to experiment with and expand the orchestral palette. These developments occurred alongside technical advancements of instruments, which improved the expressive capability of the instruments and their combinations. Novel orchestral textures and effects were exploited and used as a structural and expressive medium, especially in opera. Rossini, in particular, revitalized and expanded the orchestral crescendo in order to create a dramatic effect. Todd suggests that Wagner combined the best of the eighteenth-century symphonic orchestra and the nineteenth-century dramatic orchestra, even employing an expanded orchestral crescendo in the prelude of *Die Walküre.* Importantly, orchestration aquired a dramatic rather than purely structural function. Along these lines, Rimsky-Korsakov ([1912] 1964, 139) references sudden or gradual rates of orchestral changes, adding that the goal is to create musical tension.

In the next section, I examine the orchestral crescendo and orchestral contrasts, tracing their usages from the eighteenth century into the early twentieth century, with emphasis on their structural and expressive functions. Works consulted include historical and contemporary treatises by Adler (2002), Berlioz (MacDonald [1855] 2002), Brant (2009), Carse ([1925] 1964), Kennan and Grantham (2002), Piston (1955), Prout ([1899] 2003), Read (1979), and Rimsky-Korsakov ([1912] 1964). It is important to note that orchestration treatises mainly focus on practical considerations, such as individual instrument ranges, tone qualities, doublings and common uses, intermixed with short excerpts by the masters to be studied and emulated. I assembled insight into large-scale, expressive orchestral crescendi and textural contrasts drawing from passages with an emphasis on technical or didactic advice.

Orchestral crescendo

Spitzer and Zaslaw (2004) assert, "The crescendo was the orchestral effect *par excellence* of the eighteenth century, or at least it was the effect that excited the most comment" (457). The earliest examples of the crescendo can be traced to programmatic pieces and opera overtures, such as those by Jean-Philippe Rameau in the 1730s and Niccolò Jommelli in the 1740s (Todd 1986; Spitzer and Zaslaw 2004). Jommelli began to score crescendi in non-programmatic contexts as well. In his overture to *Attilo Regolo* (1753), a similar approach to the opening of Haydn's "Le Matin" can be observed: the strings enter first, followed by the staggered entries of the brass (on pedal point) and oboes.[5] In addition to the crescendo in dynamics and instrumentation, the onset density also increases through the incorporation of shorter note values and tremolo, building to the climax at the close of the overture.

During the middle of the eighteenth century, the Mannheim composers further experimented with the orchestral crescendo, popularizing the effect to the point of notoriety (Todd 1986; Spitzer and Zaslaw 2004). Their experimentations with gradations in dynamics and instrumentation were further developed by composers later in the century. Todd notes that the systematic and extended additions in texture, particularly with the winds, provide evidence of the increasing interest in orchestration as a means to define the formal structure.

The reverse effect of the orchestral diminuendo was also an important tool for composers. One of the most famous examples of an orchestral diminuendo is in the Finale of Haydn's "Farewell" Symphony 45. The programmatic and extramusical aspects of this symphony have been well documented (Landon 1955; Hodgson 1976; Webster 1991). Spitzer and Zaslaw indicate that the orchestral diminuendo for classical composers was less common, which they attribute to the difficulty in distinguishing the effect from a natural decrescendo associated with a phrase-end. David

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[5] See score and brief commentary in Spitzer and Zaslaw (2004, 460–461).

Huron observed this asymmetry in a score-based analysis of dynamic markings in piano music and of voice entries in baroque polyphony, indicating that crescendos are more frequent and last longer than diminuendos. He suggests that this finding is consistent with physiological aspects of attention in which increases in stimulus intensity level are more effective than the equivalent decreases.[6] More recently, Dean, Olsen, and Bailes (2013) investigated the acoustic intensity patterns in performances across several different genres, and they found that rises in intensity are actually shorter than decreases, with no difference in the rate of occurrence between the two. The distinction between score-based analyses and performance-based analyses will be addressed further below.

As discussed above, nineteenth-century composers continued to develop and expand the orchestral crescendo. Rimsky-Korsakov ([1912] 1964) provides a section on crescendo and diminuendo in his chapter on composition, distinguishing between short and extended usages. He notes that the instruments enter successively beginning with the strings, followed by the woodwinds, and finally adding the brass:

> Short crescendi and diminuendi are generally produced by natural dynamic means; when prolonged they are obtained by dynamic means combined with other orchestral devices … Prolonged orchestral crescendi are obtained by the gradual addition of other instruments in the following order: strings, wood-wind, brass. Diminuendo effects are accomplished by the elimination of the instruments in the reverse order (brass, wood-wind, strings) (Rimsky-Korsakov [1912] 1964, 151).

The orchestral crescendo is often cited as a useful technique in building a climactic effect. In *The History of Orchestration,* Adam Carse ([1925] 1964) explains:

> It was the early nineteenth century composers who first began to understand how to build up an extended crescendo by adding part after part until all the instruments of the orchestra were engaged. The sense of growing power in these cumulative crescendi was a sensation in orchestration (231).

Similarly, Gardner Read (1979) describes the climactic effect of the expanded orchestral crescendo experienced by audiences:

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[6] Physiological orienting responses related to attention involve increases in skin conductance, pupil dilation, heart rate deceleration and other effects (Huron 1992).

> But Rossini more nearly approached the status of a significant orchestrator in his exploitation of the long orchestral crescendo, contriving a general increase in dynamic strength by successive instrumental instances adding up to a rousing orchestral tutti. The aurally satiated sophisticate of the twentieth century may not be immediately impressed by such modest theatrics, but to Rossini's audiences they must have seemed like an eruption of Vesuvius (59).

The conceptualization of the orchestral crescendo in historical and contemporary treatises lags behind practice. The concept of an orchestral crescendo or diminuendo appears to be so ubiquitous and self-evident that some texts mention the effect in passing without specifically defining the concept. For example, Walter Piston (1955) introduces the cymbal in his discussion of percussion instruments by stating, "Having a dynamic range from the softest whisper to a triple forte of incandescent power, the cymbal roll is a brilliant means of adding excitement to the orchestral crescendo" (310). However, no introduction of the concept or description of an orchestral crescendo is offered elsewhere. In the "Special Devices" section of *The Technique of Orchestration,* Kennan and Grantham (2002) describe how a "sneak-in" can be used in conjunction with an orchestral crescendo, but they do not consider that the concept requires further comment: "Of course the process of adding or withdrawing instruments for the purposes of creating an orchestral crescendo or diminuendo is used frequently and thus is not in the 'special' category" (325).

Textural and timbral contrasts

As discussed above, timbral contrasts (e.g., alternation of strings and winds) and textural contrasts (e.g., alternation of full forces and a smaller subgroup) were often used by composers in the eighteenth century as a method to define structural boundaries. Todd outlines Haydn's experimentations in this manner using wind and string oppositions that coincide with formal subdivisions, thereby highlighting certain passages through the alternation of timbre. In Spitzer and Zaslaw's description of orchestral effects, those of variety and nuance, in particular, provide contrast through timbral changes and reduced scorings. Given the dominance of the string section, musical segments could be featured through the alternation with a wind soloist or wind choir. *Reduced scorings* (e.g., from tutti to solo violin) and *echo effects* (dynamic and textural adjustments) were also very effective at providing contrasts through changes in instrumental texture and volume. The effects of unity and grandeur use the power of the orchestra to produce contrasts. For example, the *grand pause* uses silence to draw the listener's attention to the preceding or following sound mass. Stamitz and others used silence to flank instances of other effects such as the *coup d'archet* (synchronized bow stroke) and *tutti chords* in order to enhance the resulting impression of the full orchestra.

Dolan (2013) proposes that many of Haydn's symphonies begin with the notion of orchestral growth, which she describes as progressing from "a small 'non-orchestral' sound to a big, celebratory tutti" (104). She notes that most of Haydn's main themes in the exposition begin *piano* with the strings or solo instruments, and then dramatically build to full forces. I suggest that Dolan is actually describing two types of orchestral growth. The difference lies in the manner in which the orchestral tutti arrives: a gradual swell or a sudden entrance. For the latter type, the process of growth occurs in two distinct stages. In the first stage, material is presented in a small group of instruments, often in the strings or the alternation of the woodwinds and strings. The second stage involves the sudden entrance of the tutti. This process of orchestral growth, then, is different from the orchestral crescendo, which involves a gradual progression (as shown in the "Le Matin" example). In both cases, Dolan considers that the drama of the movement is directly related to the varied orchestration of the extended accumulation, which builds forward energy and excitement. I argue that this notion of sudden textural or timbral contrasts as a goal-directed process marks a distinction from its description as a purely structural boundary marker by Todd, as well as Spitzer and Zaslaw.

Contemporary orchestration treatises provide examples of sudden timbral and textural contrasts for climactic purposes. Many describe the importance of providing contrast through differences in colour among the instrumental families and through differences in texture between a soloist and a group. In the section on the "Climactic Use of the Brass," Samuel Adler (2002) explains, "One of the most successful ways to build an orchestral climax is by holding back the use of certain instruments in order to save a certain color for a specific event" (413). He lists several examples of this technique using an alternation of instrumental choirs and brass flourishes. Later, in his discussion of percussion, Adler (2002) picks up on this line of thought and adds, "Many composers have used the percussion section to build a climax or help sustain other kinds of repeated gestures. Alternatively, the percussion may be held back until the climactic moment" (513).

In addition to the notion of orchestral expansion, Adler provides examples of the sudden reduction to a "contrast or relief choir" of instruments, such as the abrupt change from full forces to the woodwind or brass families. Similarly, Kennan and Grantham's (2002) chapter on "Special Devices" outlines the division of orchestra into groups for antiphonal effects and broad contrasts of weight or colour. In a section on "Special Dynamic Arrangements," they describe an effective technique in which the sudden reduction of instruments at *forte* is immediately followed by a different, smaller group of instruments playing *piano:*

> An instrument or a group of instruments that has been playing *forte* drops out, and as it does so, another instrument or group enters *piano* on the last note. Stravinsky appears to have been especially fond of this device; two examples from *Petrouchka* follow, and numerous others could be quoted, including one from *Agon* in which three double basses playing harmonics take soft sustained tones as the other instruments drop out – a magical effect (Kennan and Grantham 2002, 325).

These descriptive fragments point to the use of and general awareness of orchestration changes—both gradual and sudden, as well as adding and removing instruments—for structural and expressive purposes, but a clear taxonomy and a conceptual framework related to their function and perception is still needed. Although some of the contemporary treatises provide musical examples and brief descriptions of the orchestral crescendo and timbral/textural changes, they do not fully consider how they have evolved beyond small-scale orchestral effects and how they have taken on new functions within the musical fabric. How do score-based and performance-based musical features, such as dynamics, onset density, ambitus, and harmony, interact with orchestration and texture? What are the possible expressive effects? The lack of theory or guiding principles leaves the orchestrator and theorist with a limited knowledge of these processes.

TYPOLOGY OF ORCHESTRAL GESTURES

Four types of orchestral gestures

Our understanding of large-scale, goal-oriented orchestral changes would benefit from being framed within the literature on musical gestures. Through this lens, the eighteenth-century effects could be viewed as proto-orchestral gestures. As a starting point for inquiry, I propose four types of orchestral gestures in which large-scale timbral and textural changes occur in a coordinated, goal-directed manner. As shown in a visual representation in Figure 2-2, the types are defined by changes in instrumentation, organized into a two-by-two design based on time course (gradual or sudden changes) and direction (additive or reductive changes). The x-axis represents time and the y-axis represents the number of instrumental parts that are engaged. Each gesture adds or removes instruments in a gradual or sudden process over time. The four types relate to the descriptions above of an "orchestral crescendo" (gradual addition), the reverse process (gradual reduction), and timbral contrasts including a rapid switch to tutti forces (sudden addition) and the drop-off to a contrast choir or soloist (sudden reduction). Conceptualizing orchestral shaping as a type of musical gesture, rather than effects or techniques, captures their goal-directed sense of motion and underlines their structural and expressive role on the musical experience as carriers of emotional force.

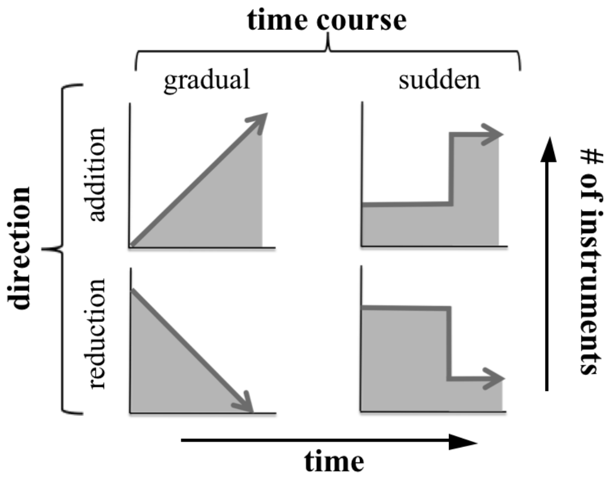

Figure 2-2. Four types of orchestral gestures

Musical gestures

Within the past few decades, there has been increasing interest in musical gestures, which have been studied from an embodied perspective within several frameworks in relation to communication, control, and metaphor.[7] The concept of gesture is complex yet intuitive due to its deep roots in biology and perception. Across all research, the grounding assumption is that musical gestures involve movement that is semiotic in nature and becomes marked as significant by a perceiver (Gritten and King 2006a).

Under the umbrella of gesture as metaphor, Robert S. Hatten's (2004; 2006) theory of musical gesture is the seminal work in the field. Musical gestures are biologically and culturally grounded in human movement and communication—not only the sound-producing actions in performance but also "the characteristic shaping" of the sounds that coveys expressive meaning (Hatten 2004, 93). Through the interaction of a range of human perception and motor systems,

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[7] Three interdisciplinary volumes have been published in the last decade, covering diverse research topics (Godøy and Leman 2010; Gritten and King 2006b; Gritten and King 2011).

listeners synthesize musical elements that shape motion through time into significant, expressive events.

As emergent gestalts, musical gestures contain and convey motion, emotion, and intentionality through purposeful coordination and fusion of separate elements (e.g., timbres, articulations, dynamics, tempi, and pacing) into a temporal continuity of shape and force. Hatten argues that gestures may be inferred from musical notation within the conventions of a given musical style and from musical performances even without visual cues from the performer. He explains,

> In Western musical styles a kind of virtual gravitational field or vectoral space provides an analogue to the forces working on the human body in the physical space… These fields or spaces provide comparable environmental constraints against which freely willing, energetic musical gestures can begin to feel like gestures on the body. As soon as that happens, we can speak of a kind of *agency*, especially when a series of gestures appear to cohere as an intentional or goal-directed sequence, progression or discourse (Hatten 2006, 3).

Hatten proposes that dynamic fields are referenced through two primary frames: meter for virtual orientation (i.e., sense of rising and falling) and tonality for melodic and harmonic tension. Within these frames, the animating force of an agent can be implied through the effort required to overcome forces in the musical environment as an analogy to the effort exerted by our bodies to overcome physical forces. I argue that orchestral gestures may also be referenced within a textural and timbral frame, which can provide a sense of agency through the growth and power as one governing body, as well as through textural and timbral contrasts as opposing forces.

The prototypical musical gesture occurs in the perceptual present and can be hierarchically organized. Hatten provides an example of a slow introduction, which consists of local-level gestures but also acts as a gestural anacrusis to an Allegro section. Compared to a prototypical gesture, the four types of orchestral gestures outlined in this study would occur on a higher hierarchical level, as they are shaped over the course of several measures or comprise full movements. These types do not, however, preclude the possibility of other types of orchestral gestures occurring at a local level.

Hatten suggests that one of the most important gestural functions is thematic, occurring in the perceptual foreground as a thematic entity and used as the subject of musical discourse. He notes that thematic gestures typically capture the expressive character of the work and carry emotional force, thereby aiding in interpreting and understanding musical meaning. Importantly, thematic gestures may be subjected to ongoing development, coordinating the expressive direction of the work. I suggest that the gradual types of orchestral gestures relate to thematic gestures as higher-order counterparts within the prevailing musical processes of the work. The gradual addition gesture representing growth and the gradual reduction gesture representing abatement organize the foreground processes into an overarching expressive trajectory shaped by the orchestration.

Sudden orchestral gestures relate to Hatten's (2006) notion of a rhetorical gesture, which "marks a disruption in the unmarked flow of events at any level of the musical discourse" (6). This type of gesture involves pauses, changes, or shifts that are sudden or unpredicted, often highlighting "tonal reversals or textural undercuttings" (Hatten 2004, 136). The appropriation of rhetoric as a model for music composition has a longstanding history, particularly within the German music-theoretical tradition in the Baroque era (McCreless 2002). Given evidence of the firm rooting of rhetoric in the terminology and metaphors for musical structures and processes even in the early nineteenth century (Sisman 1994), Hatten (2006) argues for the applicability of rhetorical concepts in interpretation, particularly in relation to gesture.[8] In his analysis of a Mozart Piano Sonata, Hatten (2004) suggests that the interruption of the musical flow with a sudden silence evokes the rhetorical gesture of *aposiopesis* or *abruptio* (312); the former term refers to an intentional and expressive use of ensuing silence, and the latter term denotes a sudden and unexpected break or intentional

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[8] It is also interesting to note that McCreless (2006) speaks of rhetorical intensity and rhetorical flourishes in descriptions of climactic gestures within nineteenth-century and twentieth-century music.

suppression (Bartel 1997). Therefore, the gesture represents a rhetorical rupture within the prevailing musical context. This notion aptly characterizes the large-scale dramatic textural drop-off of the sudden reduction gesture, which marks the breakdown of musical processes, often as a dramatic structural subversion. Although the moment after the drop-off may not give way to complete silence, the suppression of forces provides a sense of restraint in the resulting atmosphere. The sudden addition orchestral gesture also relates to Hatten's concept of a rhetorical gesture through the disruption of an abrupt textural shift. Additionally, the use of silence before the climactic addition of full forces connects to the rhetoric of *aposiopesis* and *abruptio*.

The term "orchestral gesture" has been used informally in previous scholarship to denote an expressive shaping by the orchestra, but has not been clearly or sufficiently defined.[9] For example, Dolan (2013) uses the term without further comment in reference to Haydn's opening gesture of growth in several symphonic examples. In his study of instrument combinations in nineteenth-century orchestral works, Johnson (2011) provides one of the rare explicit definitions:

> For the purposes of this study, orchestral gestures are defined as devices composers use to repeat, vary and connect phrases. Gestures range in length from several measures to a whole section of a piece. The "Rossini crescendo" and Stravinsky's sudden changes of block textures are examples of orchestral gestures. Gestures not only function as articulators of musical form, but they also carry qualities such as a "smooth build" and "sudden interruption." A model of orchestration that combines theories of timbre and gesture has the potential to richly characterize the instrument combination patterns in symphonic works (3).

Although his definition aligns with many facets of the research presented here, Johnson's approach of analyzing random static snapshots of orchestral sonorities is antithetical to an understanding of orchestral gestures that necessarily evolve over time. Without considering the musical context, Johnson's model of instrument combination only reflects abstract, isolated arrangements. Therefore,

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[9] An informal search for "orchestral gesture" retrieved fewer than 1000 results on Google and 45 results on Google Scholar. The vast majority of authors do not define the term, but employ it to describe the shape of a motive or phrase played by the orchestra (e.g., rapid ascending scale as a characteristic orchestral gesture).

his claim that the proposed model groups together instruments based on the goals of orchestral gestures has not been substantiated.

One of the most important aspects about the research on gesture is its inherent link to perception. Musical gestures, though stylistically mediated, are richly informative and perceptually immediate (Zbikowski 2011; Hatten 2004; Hatten 2006). Hatten (2006) explains:

> But it is the immediacy of biologically typed gestural meanings – anger, grief, joy, disgust, surprise – that allows us to connect viscerally at a basic level with music that may be culturally or historically distant from our own time…" (10).

Musical gestures, grounded in affect and its communication, embody the characteristic shaping that conveys expressive meaning. Therefore, musical gestures have the capacity to carry emotional force. The expressive potential of orchestral gestures requires further research and will be investigated in the following sections.

ANALYSES OF ORCHESTRAL GESTURES

I analyze examples of orchestral gestures using a new visualization tool to uncover the inherent expressive meanings of the four types of orchestral gestures. To investigate the effects of orchestral gestures on the listening experience, a companion paper outlines an exploratory experiment that investigates listeners' emotional responses over time in relation to these musical excerpts.[10] I selected three excerpts for each of the four types of gestures (as shown in Table 2-1) to be analyzed and used as stimuli in a perceptual experiment. The musical passages are characterized by one overarching orchestral gesture and are 1 to 3 minutes in duration in order to provide a meaningful listening context. Based on research in orchestration texts, I searched for examples in the orchestral repertoire of the late-nineteenth and early-twentieth centuries where large-scale orchestral gestures were most likely to be found. One recording for each excerpt was chosen

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[10] (Goodchild, Wild, and McAdams 2016) [Chapter 3]

qualitatively as a representative performance due to power of expression and the use of similar recording techniques.

Table 2-1. List of stimuli by gesture type, excerpt number (number) and Appendix number for visualization (A+number), composer, piece, measure numbers (mm.), recording, and duration (min:s).

Type	#	Composer	Piece	mm.	Recording	Duration
Gradual Addition	1 A1	Gustav Mahler	Symphony 1, III (1888)	1-32	New York Philharmonic, conducted by Leonard Bernstein, Sony Classical, 2001	1:50
	2 A2	Gustav Mahler	Symphony 2, I (1894)	254-302	New York Philharmonic, conducted by Leonard Bernstein, Sony Classical, 2001	2:28
	3 A3	Jean Sibelius	Symphony 1, I (1900)	1-96	Lahti Symphony Orchestra, conducted by Osmo Vanska, BIS, 1995	2:53
Gradual Reduction	4 A4	Modest Mussorgsky/ Maurice Ravel	*Pictures at an Exhibition*, "Bydlo" ([1874] 1922)	39-64	Berliner Philharmoniker, conducted by Herbert von Karajan, Deutsche Grammophon, 1964	1:59
	5 A5	Gustav Mahler	Symphony 2, I (1894)	80-116	New York Philharmonic, conducted by Leonard Bernstein, Sony Classical, 2001	2:03
	6 A6	Richard Strauss	*Ein Heldenleben,* III (1898)	331-353	London Symphony Orchestra, conducted by Sir John Barbirolli, EMI Classics, 1996	2:09
Sudden Addition	7 A7	Ralph Vaughan Williams	*London Symphony*, I (1914)	8-53	Royal Liverpool Philharmonic Orchestra, conducted by Vernon Handley, EMI Classics, 2011	2:42
	8 A8	Richard Strauss	*Tod und Verklärung,* II (1889)	360-395	London Symphony Orchestra, conducted by Jascha Horenstein, Chandos Records, 1987	1:35
	9 A9	Claude Debussy	*La Mer*, I (1905)	122-141	Berliner Philharmoniker, conducted by Simon Rattle, EMI Classics, 2005	2:02
Sudden Reduction	10 A10	Gustav Holst	*The Planets*, "Uranus" (1916)	193-236	London Philharmonic, conducted by Sir Adrian Boult, EMI Classics, 2002	1:19
	11 A11	Anton Bruckner	Symphony 8, I (1890)	221-270	Wiener Philharmoniker, conducted by Pierre Boulez, Deutsche Grammophon, 2000	1:40
	12 A12	Antonín Dvořák	Symphony 9, I (1893)	200-286	Houston Symphony, conducted by Christoph Eschenbach, EMI Records/Virgin Classics, 2000	1:26

Visualizations

I developed a visualization tool in order to facilitate the analysis of orchestral gestures. This exploratory approach creates a synoptic view of the excerpt by graphing together musical features for visual examination. Figure 2-1 above provides a score-based perspective of the excerpt, but lacks crucial performance details. As a result, the dynamic markings on the score provide only a general understanding, but not the precise dynamic levels achieved through the combination of orchestral forces over time. Additionally, the figure is not able to convey any information about the shaping of tempo and pacing. Therefore, I selected three-score based features (instrumental texture, onset density, and contour) and three performance-based features (loudness, spectral centroid, and tempo) due to their importance in descriptions of orchestral gestures in treatises and in similar research (Adler 2002; Schubert 2004) and will be described further below. Harmonic and phrase-structural analyses could also be incorporated into this type of visualization; however, the excerpts analyzed here comprise several minutes of music so this level of detail was not practical to include at this stage. As listed in Table 2-1, the visualizations for all 12 excerpts can be found in Appendix A.

Data processing details are outlined in detail in the companion paper.[11] Tempo, texture, onset density, and contour were manually coded. Tempo indicates the beat-to-beat pacing changes in beats per minute (bpm). As outlined by Schubert (2004), instrumental texture was objectively coded as the number of independent parts sounding at each beat. The texture parameter is displayed as a stacked bar graph with the instrument family indicated by colour, thereby providing a measure of the textural density of each family and its evolution over time.[12] Onset density counts the number of onsets or attacks per beat, distinguishing between sustained pitches or long note values (low onset density) and short note values or rapid figuration (high onset density). The contour variable tracks the *ambitus* (notated spread between the lowest and highest instrumental parts) at every beat.

Loudness and spectral centroid were extracted from the commercial recordings with PsySound3 (Cabrera, Ferguson, and Schubert 2007). As a measure of the performed changes in

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[11] (Goodchild, Wild, and McAdams 2016) [Chapter 3]

[12] Doublings in the same instrument family (e.g., flute 1 and 2) are counted as one part. Double stops are included in the count.

dynamics, loudness is the subjective impression of the intensity of sounds measured in sones.[13] The values were calibrated to the measured sound pressure level in dB of each excerpt played in a room representing a concert setting.[14]

Timbre is a multidimensional phenomenon and a complex musical parameter. One perceptually relevant dimension of timbre is the often-cited correlation between spectral centroid (center of mass of the frequency spectrum) and the perceived brightness of a sound.[15] Using PsySound3, the spectral centroid was extracted in Hz (frequency). Spectral centroid is not completely independent of the other musical parameters as it also conveys information about pitch height and covaries with loudness (i.e., playing effort).

Each musical parameter was resampled every half second to create a time series—data points measured over successive half-second intervals.[16] The time in seconds from the beginning of the excerpt and the measure numbers are indicated on the x-axis.[17] The musical-feature graphs are stacked for visual examination.[18] The emotional intensity ratings are described in the companion paper and are outside the scope of this paper.[19]

Dolan (2013) has also recently created orchestral graphs that track the score-based dynamic levels of each instrument in excerpts of Haydn's symphonies. The visualizations developed for the present study have several advancements: the inclusion of multiple score and performance features,

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[13] One sone is the perceived loudness of a 1000-Hz tone presented at 40 dB SPL. The sone unit is proportional to loudness (i.e., a doubling of sones corresponds to a doubling of loudness). The sone scale was created to provide a linear scale of loudness and was obtained by a perceptual ratio scaling technique. On the scale, silence approaches 0 sones and the experiment excerpts were played to a maximum of 119.8 sones (97 dB). For more information, see Yost (2007, 189–190).

[14] The experimental design is described in the companion paper (Goodchild, Wild, and McAdams 2016) [Chapter 3].

[15] For a review see, McAdams (2013).

[16] The data processing was conducted in MATLAB (Mathworks, Inc). All graphs were created in Excel (Microsoft, 2013) and Illustrator (Adobe Systems, 2007).

[17] As described in the companion paper, the first two seconds of data were cut for each excerpt, except for excerpt 3 in which the first five seconds were cut. The cut was due to fact that the beginnings of the recordings have only a few instruments playing, which created a spurious high spectral centroid from the background noise of the recording. (Goodchild, Wild, and McAdams 2016) [Chapter 3]

[18] The scale of the y-axes for spectral centroid, loudness, tempo, texture, and onset density is adjusted based on the excerpt. The scale of the contour parameter is constant between C_1 and C_8 for all graphs.

[19] (Goodchild, Wild, and McAdams 2016) [Chapter 3]

as well as the ability to view the evolution of both instrumental texture and rhythmic activity (onset density).[20] The simultaneous development of visual representations of orchestration demonstrates the critical need of tools for orchestral analysis.

The visualizations provide a method to compare and contrast examples in order to develop a better understanding of how composers sculpted musical features—orchestral texture, rhythmic activity, brightness, dynamics, and pacing—that are largely neglected in traditional music analysis. It must be noted, however, that the visualizations cannot be used for inferential analytical techniques, but they can be used for interpreting musical parameters and finding patterns by compiling diverse types of data in a meaningful way.

In the following section, I analyze three examples of each type of orchestral gesture and demonstrate the application of the visualization tool. Although I reference tonal and structural aspects, my analyses privilege details regarding the orchestral shaping over time.

Gradual addition

Mahler, Symphony 1, III

A characteristic example of a gradual addition gesture is from the opening of the third movement of Mahler's Symphony 1 (see Example 2-2 and the visualization in Appendix A1). Mahler depicts a hunter's funeral march based on the folk melody "Bruder Jacob," also known as "Frère Jacques," scored in the minor mode. Orchestration manuals indicate that an "orchestral crescendo" normally begins with the strings, followed by the woodwinds, and finally the brass; however, the texture parameter in the visualization reveals that Mahler elaborates this process in several ways. The solo timpani (purple in the visualization) ominously commences the excerpt alternating between the

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[20] The similarity between Dolan's orchestral graphs and my visualizations is an instance of multiple discovery, in which an invention is independently and simultaneously created. I have been developing my visualizations since 2010. Early versions were presented at the Society for Music Perception meeting (Goodchild et al. 2011).

tonic and dominant pitches. The atmosphere continues to build in intensity as solo bass instruments of each family enter successively in canon: double bass (m. 3), bassoon (m. 9), and french horn (m. 21). The canon process accelerates as each line is strengthened progressively with the addition of instruments within each family in higher registers. The textural and rhythmic activity intensifies with the introduction of the countermelody in the oboe beginning in measure 19. The climax of the excerpt occurs with the final canonic entry in the horns, doubled by the harp, and the return of the countermelody in the oboe and clarinet at measure 29.

As shown in the visualization, the musical features of onset density, loudness, and spectral centroid increase linearly overall, while texture increases almost exponentially over time. In terms of ambitus, Mahler maintains a narrow range in the bass register for the first half of the excerpt and then slowly expands the upper range. The lowest voice alternates between tonic and dominant, dropping down to the lower octave in the second half of the excerpt.

On a large-scale level, the gradual addition gesture provides a sense of orchestral growth—grounded by the bass ostinato and supported by the tonic pedal point in the tam-tam and tuba (mm. 23-32)—with a coordinated thickening of the instrumental texture, increase in rhythmic activity, expansion of the ambitus, and augmentation in volume (loudness) as a continual, methodical process. On a local-level, the juxtaposition of the formerly jovial folk song in the minor mode with the fanfare-like countermelody creates a sense of tragic irony. This emergent expressive meaning is intensified as the large-scale orchestral gesture directs the dramatic trajectory of the excerpt.

Example 2-2. Mahler, Symphony 1, III, mm. 1-32

Example 2-2 (continued)

Example 2-2 (continued)

Mahler, Symphony 2, I

For comparison, another example of the gradual addition type is Mahler's Symphony 2, I, mm. 254-302 (Appendix A2).[21] Although creating similar overall shape of increasing textural density, he constructs the orchestral crescendo in a different manner. Rather than a systematic addition of part after part, Mahler accumulates the instrumental fabric in a fragmented manner, with instruments dropping out before entering again later with greater numbers. The excerpt begins with an ominous, roaming melody with a limping rhythmic pattern in the cello and bass at *pianissimo.* At measure 258, violin 2 and the viola join the strings while the English horn enters with a forlorn melody featuring a sigh gesture. In Example 2-3 (mm. 261-265), the English horn, violin 2 and viola drop out of the texture and are replaced by the flute with a triplet counter-motive, the trumpet and trombone with an elaborated version of the sigh melody, and violin 1 joining the low strings. These adjustments in instrumental combinations cause peaks and dips in spectral centroid, indicating the timbral changes in brightness. The transfer of melodic material between instruments adds colourful exchanges in the foreground while the low-string figure builds in intensity as the excerpt progresses.

Several musical features coordinate to create the climax at the end of the excerpt (m. 291ff). Leading up to this point, there is a prolonged trajectory of orchestral growth. In terms of ambitus, the excerpt begins in parallel octaves in the low register between the cello and double bass and then expands to a range of over four octaves between the highest and lowest voices. The loudness, tempo, onset density and texture build gradually. The arrival point at measure 291 initiates a more rapid intensification, signaled by the *tempo rubato* in measure 289, followed by a markedly faster tempo and a spike in orchestral thickness and onset density. The extended use of percussion and protracted period of maximal loudness also contribute to the expressive drama of this gesture.

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[21] Note, there are breaks in the high contour parameter because only the bass instruments are present.

Example 2-3. Mahler Symphony 2, I, mm. 261-265

Sibelius, Symphony 1, I

Appendix A3 contains the visualization for the gradual addition at the beginning Sibelius's Symphony 1, I (mm. 1-96). This example demonstrates a remarkable scoring of the gradual addition over several stages. For ease of reference, Figure 2-3 shows the texture, onset density, and contour parameters. The shaping of the orchestral crescendo comprises four phases, which correspond to the structure of the introduction and subdivisions of the main theme (Brown 2007). In the Mahler examples, the gradual additions began with a solo string instrument or small group of strings in the low register accompanied by the timpani. Here, the initial phase of the crescendo is expanded to 28 measures and involves the clarinet and timpani (mm. 1-16) and clarinet solo (mm. 17-28). The solitary, desolate clarinet melody over the rolled timpani pedal builds in tension, anticipating the entry of other members of the orchestra.

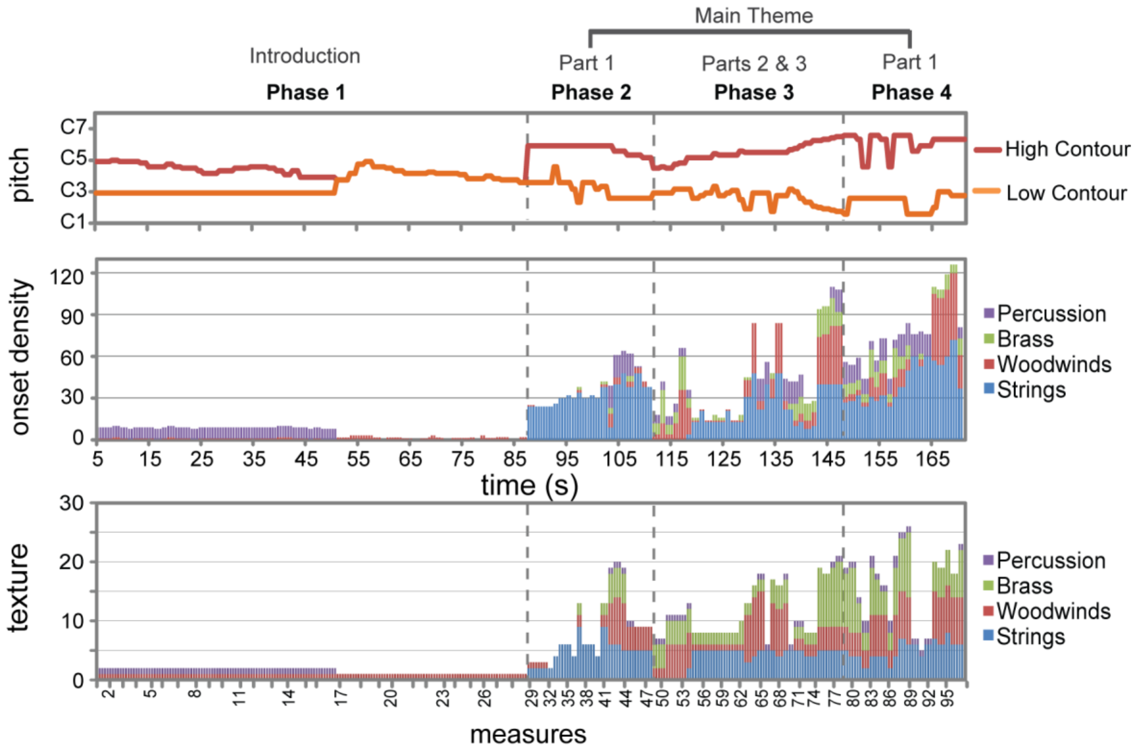

Figure 2-3. Visualization of texture, onset density and contour parameters for Sibelius, Symphony 1, I, mm. 1-96

In the second phase (mm. 29-48), the entry of the main theme part 1 is launched by the change to tempo *Allegro energico* and by the tremolo figure in the upper strings, which creates a shimmering brightness (see the spike in the spectral centroid in Appendix A3). As shown in Figure 2-3, the first part of the main theme follows a miniature orchestral swell and decrease in terms of orchestral texture, onset density, and ambitus.

The third phase (mm. 49-78) begins with the strings dropping out, which commences an antiphonal dialogue between the woodwinds and strings (shown in the texture parameter with spikes of red). The exchange leads to chromatic expansion of the ambitus (mm. 69-78), causing a peak in onset density and swelling to the return of the main theme part 1 in full forces.

The final phase (mm. 79-95) initially reduces the intensity of the musical parameters in order to build to the final climax at measure 93. In terms of loudness, the dynamic level dips and rises to the final peak towards the end of the excerpt. Similarly, the spread between lowest and highest parts narrows before expanding again, while the onset density drops and then gradually increases once more. The orchestral texture builds in a fragmented manner, and then thins to the strings just before the arrival point.

Through each stage of the orchestral crescendo, Sibelius plays with the orchestral fabric in sequences of rising and falling intensity. The dramatic shaping initially pits the solitary clarinet against the increasing power of the orchestral forces. The expressive impact of each successive triumphant arrival point is sculpted through the large-scale trajectory of the gradual addition.

Gradual reduction

In my search for orchestral gestures in the repertoire, unambiguous examples of large-scale gradual reductions were more difficult to find in comparison to gradual additions. This finding directly echoes Spitzer and Zaslaw's conclusion that orchestral decrescendi are less common than crescendi in the classical era. I suggest that Romantic composers do not frequently draw out the gradual reduction gesture in the same way as their expansive gradual additions. This may be related to Huron's notion discussed above in terms of physiological aspects of attention, in that increases in stimulus intensity are more effective than decreases. Therefore, composers may have avoided protracted decreases in intensity in order to retain the dramatic force and the listeners' attention as a result.

The three examples analyzed here begin with a swell that prepares for the process of gradual reduction. Unlike the gradual addition excerpts, the other musical features do not necessarily coordinate with the trajectory of abatement in instrumental texture. As a result, the perceptual effect is not simply the reverse process of the gradual addition.

Mussorgsky/Ravel, Pictures at an Exhibition, "Bydlo"

Appendix A4 contains the visualization for Ravel's orchestration of the ending of "Bydlo" from Mussorgsky's *Pictures at an Exhibition* (mm. 39-64). This excerpt contains the most archetypical example of gradual reduction found for this study. The gesture depicts an oxcart passing the listener and receding into the distance. The musical parameters, particularly loudness, onset density, and texture, decrease steadily to the end of the excerpt. The ambitus contracts from four octaves down to one octave at measure 47 and then down to a single instrument at the end of the excerpt. The tempo remains mainly steady throughout, with a more pronounced slowing at the end. The onset density variable has a resolution at the level of the sixteenth note; therefore, the spikes on each eighth-note beat represent the reinforcement of the steady footsteps of the oxen in the majority of the instruments.

The portrayal of the oxcart receding in the distance is extremely effective. The musical texture reduces in stages, first a large drop-out at measure 38 and another at measure 47, followed by a more gradual process. As shown in Example 2-4, Ravel progressively orchestrates a "low-pass filter," gradually removing the higher-frequency instruments. Originally in the upper range of the tuba, the theme returns in the low range of the muted cornet, fading out as the implied distance increases. The rhythmic details are progressively stripped, leaving only the pitches on the downbeats in the bass clarinet, castanets, and low strings. The overall effect of the gradual reduction is a gesture of abatement, providing a concluding function of the movement.

Example 2-4. Mussorgsky/Ravel, "Bydlo" from *Pictures at an Exhibition*, mm. 53-64.

Mahler, Symphony 2, I

Appendix A5 contains the visualization of the gradual reduction in Mahler's Symphony 2, I (mm. 80-116). The first six measures of the excerpt build up the instrumental forces to prepare for the reductive function of the gesture. In the main process of the gradual reduction (mm. 87-96), the spectral centroid, loudness, and texture parameters diminish through a sequential phrase-structural process. Before completely dying out, the final phase of the gradual reduction is expanded (mm. 97-116). The repeated descending chromatic motive from the local tonic to dominant (three quarter notes plus triplet eighth-notes) creates an ostinato in the cello and bass, while the upper parts enter in various guises and rework thematic motives causing peaks of brightness. During this elongated final stage of the gradual reduction, the gestural trajectory is held back, creating a sense of stasis through the ostinato and repeated sigh motive, low onset density, steady tempo, and wide ambitus. Towards the end, the ostinato and the motivic material break down, fading out to the harp in its low register. In contrast to the Mussorgsky/Ravel excerpt above, the sense of conclusion is weakened, leaving the listener with a sense of suspense with an uneasy feeling of coming to rest.

Strauss, Ein Heldenleben, III

Appendix A6 contains the visualization from the third movement "Des Helden Gefährtin" (The Hero's Companion) of Strauss's tone poem *Ein Heldenleben* (A Hero's Life) (mm. 331-353). The gradual reduction gesture marks the end of the third movement as well as the conclusion of the exposition as part of the large scale sonata-form (Hepokoski 2010). Similar to the Mahler excerpt discussed above, the main process of abatement is brief (mm. 331-339), followed by a large expansion of the phase before the final fade out (mm. 339-353). The gestural force leading towards the conclusion momentarily subsides, maintaining a relatively steady dynamic level, tempo, ambitus, and onset density.

Overall, the passage exhibits a post-cadential function, acting as a series of codettas supported by a tonic prolongation. The motivic material—recalling past thematic ideas and shifting between various instruments over sustained chords—becomes increasingly fragmented and liquidated, varying the textural density of the families over time, but not the overall thickness. The excerpt finally subsides with a low sustained chord in the strings and horn, with a final chordal touch in the low register of the harp.

The excerpt expresses a prolonged sense of serene nostalgia. Marking the end of the hero's love story, the expanded final section of the gradual reduction provides a moment of reflection, reminiscing about his love before transitioning to the development section and the upcoming battle of "Des Helden Walstatt" (The Hero at Battle).

Sudden addition

The sudden addition gestures feature a goal-directed process leading up to and following the rapid addition of full forces. Unlike a sectional boundary, which marks the end of one formal unit and the beginning of another (e.g., dividing thematic units in sonata form), the sudden textural change marks a dramatic turning point as part of the expressive trajectory of the gesture.

Vaughan Williams, London Symphony, I

Appendix A7 provides the visualization of the sudden addition gesture from Vaughan Williams's *London Symphony*, I (mm. 8-53). The excerpt begins with a tranquil G-major theme with the muted strings in a slow-moving contrapuntal canon (mm. 8-19). As more instruments enter (mm. 20-30), the textural density thickens, but the overall dynamic level, spectral centroid, and onset density remain low with a hushed atmosphere.

Before the sudden addition of full forces, Vaughan Williams prepares the listener for the upcoming climactic event. The woodwinds oscillate in a slow trill, which gradually accelerates in onset density. Between measures 36-37 (shown with a bracket), the strings drop out and the woodwinds and brass ascend in an arpeggios. This anticipatory signal causes a sharp increase in loudness, spectral centroid, and onset density, as well as a slight narrowing in ambitus. After a brief pause, the full tutti suddenly enters at *fortissimo* on a dissonant chord of an augmented triad with an added major seventh. In the *Allegro risoluto, molto pesante* section (mm. 39-53), the upper parts chromatically descend, powerfully announcing the new minor-mode region. The expressive force of the sudden addition gesture underpins the tonal reversal and the interruption of the musical processes leading up to the textural shift.

Strauss, Tod und Verklarung, II

In comparison, the visualization of the excerpt from Strauss's *Tod und Verklärung,* II (mm. 360-395) in Appendix A8 illustrates a different preparation for the climactic moment of sudden addition. A suspenseful atmosphere is created by a low-pitched pedal point in the double bass and timpani, as well as a repeated two-measure unit scored with contrasting instrumental combinations (shown with blocks of different colours in instrumental texture). The section maintains a quiet dynamic, low spectral centroid, slow tempo, and only eight independent instrumental parts. The ambitus remains moderately wide, with a pedal in the double bass and a slowly moving chromatic line in the highest part.

In the Vaughan Williams example, the anticipatory signal was followed by a grand pause, building excitement for and drawing the listener's attention to the following sudden wall of sound. Here, the instrumental forces fade-out to near silence (m. 210), and then a compact anticipatory signal (shown with bracket in measure 211) leads to the entrance of full forces. Again, the signal contains ascending arpeggios with instruments entering in successively higher registers, causing a sudden increase in spectral centroid, loudness, tempo, and onset density, as well as a rapid expansion of the ambitus. The moment of sudden textural addition, therefore, is slightly blurred, winding up the dramatic action rather than delivering one forceful blow. Overall, the sudden addition gesture provides a sense of disruption in the musical discourse, breaking up the stagnant, repeated musical unit and propelling the action forward into a frenzied state.

Debussy, La Mer, I

Appendix A9 contains the visualization for the excerpt of Debussy's *La Mer*, I (mm. 122-141). The first section (mm. 122-133) begins with a subdued atmosphere, created by slow-moving strings and a melancholy melody, scored for a blended timbre with an English horn embellished by two solo celli. The second section (mm. 132-134) builds in intensity with the drop-out of the string section and a change in colour with the brass and woodwinds. The third section (mm. 135-141) commences with the climactic arrival point, scored for the full ensemble, building to the conclusion of the movement.

Initially, this gesture was categorized as a sudden addition due to the manner in which Debussy holds back several instruments (oboes, English horn, clarinets, trumpets, timpani, and upper strings) until the climactic moment at measure 135. After further consideration, the excerpt is better understood as a gradual addition gesture. Although divided into three stages, the overall expressive trajectory is one of orchestral growth. The entry of full forces is not characterized by a rhetorical effect of structural rupture, but one of expressive intensification leading towards the conclusion of the movement.

Sudden reduction

Similar to the sudden addition gesture, the drop-off of the sudden reduction does not represent a sectional boundary dividing two formal units. Instead, the gesture comprises a structural rupture in the dramatic trajectory. The moment of textural change acts as a watershed moment: the following reduced texture is interpreted as a direct consequence of the preceding processes.

Holst, The Planets, "Uranus"

Appendix A10 contains the visualization for the sudden reduction gesture of Holst's "Uranus" from *The Planets* (mm. 193-236). The excerpt begins with two iterations of a relentless march-like theme in full forces, which leads to an arrival on a *fortissimo*, climactic tonic chord in C major (m. 221). The magician's "trick" is his sudden disappearance, scored as a drop-off from the full orchestral tutti to the string section at *pianissimo* dynamic. The abrupt textural change, coupled with a significant decrease in loudness, tempo, and onset density, marks the climactic turning point in the ongoing musical processes. Following this point, a tense atmosphere is created by the hushed strings on a dissonant subdominant chord. The ominous entry of the first harp with syncopated chords clashes with the strings, and an eerie melody resonates on the second harp scored with harmonics.[22] The spread between the lowest and highest voices remains wide throughout, which highlights the sparse texture after the sudden reduction. Additionally, the low onset density and slow pace creates the effect of time being suspended, maximizing the shock of the magician's disappearance.

Bruckner, Symphony 8, I

Appendix A11 contains the visualization for the sudden reduction gesture in the first movement of Bruckner's Symphony 8 (mm. 223-225), which contributes to the tonal and thematic structural collapse bridging the development and recapitulation (Korstvedt 2000; Horton 2004). The excerpt begins with a forceful theme repeated three times, ascending by a third at each reiteration. The cadential six-four chord (m. 249) marks the arrival point of the musical processes that have abruptly come to a halt. This climactic moment is fleeting as the unresolved chord dissipates into the abyss, representing a structural breakdown. The disruption leads to a striking section that features a stark, bare texture. After the reduction of tempo leading up to the arrival point, the pace steadies and presses forward. The musical material recalls previous thematic fragments: the flute picks up the melody originally scored for the woodwinds, while the descending chromatic four-note motive reappears in the cello and bass. At measure 255, the dotted-rhythmic pattern in the brass returns in the trumpets on bare octaves. The return of the small thematic cells within the reduced texture and

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[22] Richard Greene (1995) suggests that the subdominant chord metaphorically represents magic in its "beautiful, cold and sudden" sound (64). It is interesting to note that Greene does not mention the sudden textural change, focusing instead on harmonic and programmatic aspects.

the pull to the dominant and tonic poles create an atmosphere of tension and instability. The abrupt textural shift launches the music into a new territory with a renewed sense of intentionality.

Dvořák, Symphony 9, I

The visualization of the sudden reduction gesture from Dvořák's Symphony 9, I (mm. 200-286) is found in Appendix A12. The climactic arrival (m. 257) on a leading-tone diminished seventh chord marks the breaking point of the development section after several failed attempts to move to the goal dominant. The texture reduces to a sustained chord in the brass, the theme in the oboe, and several motivic snippets in the violin. Within this hushed atmosphere, a sequence of unresolved dominant seventh chords redirects towards the threshold of the recapitulation. Similar to the Bruckner excerpt, the tempo does not slow down after the drop-off, redirecting the dramatic action forward.

DISCUSSION

In this paper, I have drawn on diverse areas of research—historical surveys of orchestral development, orchestration treatises, and literature on metaphorical musical gestures. I argue that the large-scale orchestral crescendo and expressive orchestral contrasts, previously outlined as effects or techniques, are better understood as orchestral gestures. The notion of an orchestral effect implies that the instrumentation is a secondary parameter at the service of other formal or tonal processes. In contrast, I characterize large-scale orchestral shaping as gestures, representing a goal-directed sense of motion and emphasizing their structural and expressive role in the musical discourse. The dramatic shaping of the orchestral gestures coordinates disparate musical elements, creating a sense of agency and emotional force.

I outline four types of orchestral gestures based on adding or removing instruments as a gradual or sudden process over time. The gradual addition gesture denotes a sense of developing growth, whereas the gradual reduction gesture expresses a sense of progressive abatement. In the gradual gestures, the foreground processes are organized by the overarching expressive trajectory shaped by the orchestration. The sudden gestures represent a rhetorical shift within the musical processes at hand. The moment of sudden textural change marks a dramatic turning point as part of a large-scale, goal-directed motion.

In order to move beyond anecdotal descriptions of orchestration, I developed a new type of graphical visualization. The exploratory tool provides a method to study the multidimensional interaction of instrumentation and other musical parameters within an orchestral gesture as it unfolds over time. Additionally, the visualizations provide a means for quantitative and qualitative comparison of the approaches used by different composers to shape a particular type of gesture. The incorporation of both score-based and performance-based musical elements brings the analyst closer to the experiential reality of the gestures. I suggest that the visualizations could be used in future to track differences among styles and trace the history of orchestration practices, areas which would be of interest to theorists, musicologists, composers, and other researchers.

In my analyses of the twelve examples, I attempted to uncover expressive gestural meanings by investigating the coordination of several musical parameters and their development over time. Although I consider tonal and phrase-structural musical elements, my analytical approach privileges orchestration; to this end, I incorporated various metrics—instrumental texture, onset density, spectral centroid, loudness, and tempo—which have never been integrated before. One limitation of the present study is the use of a single recording as a representative performance. In future work, multiple recordings could be consulted in order to examine the role that performance features play on the expressive force of the gestures.

The gradual addition gestures were characterized by a sense of orchestral growth; however, the four examples were constructed through different processes: methodical additions in Mahler's Symphony 1, fragmented accumulation in Mahler's Symphony 2, and distinct stages of intensification in Sibelius's Symphony 1 and Debussy's *La Mer*. In all cases, the musical processes were coordinated by a similar overall shape in terms of instrumental texture.

I suggest that the archetypical gradual reduction gesture embodies a sense of abatement. In Ravel's orchestration of Mussorgsky's "Bydlo" from *Pictures at an Exhibition*, the depiction of the oxcart receding into the distance aptly conveyed a sense of progressive lessening as a concluding function. The other two examples, however, expanded the final stage of the gradual reduction, creating a sense of prolonged stasis. The resulting gestural meanings varied based on the musical context, contributing to an expression of uneasy suspense in Mahler's Symphony 2 as well as serene nostalgia in Strauss's *Ein Heldenleben*.

The sudden orchestral gestures feature an abrupt textural shift in the addition or reduction of instruments, but also a timbral shift in the change between tutti and a subgroup of the orchestra. The sudden gestures relate to Hatten's notion of a rhetorical musical gesture in the use of a dramatic shift that disrupts the flow of events in the musical discourse. Both of the sudden addition examples by Vaughan Williams and Strauss apply the rhetorical devices of *aposiopesis* or *abruptio* through the use of silence to emphasize the textural change. Additionally, the sudden addition examples incorporate an anticipatory signal that signals the imminent dramatic event. The unexpected tutti forces mark a climactic moment that redirects the forward trajectory of the gesture. Based on these analyses, I reclassified the Debussy excerpt as a gradual addition, due to its progressive intensification of musical parameters as a gesture of orchestral growth.

The analyses also revealed distinctive uses of individual instruments. The harp was often featured within a reduced texture: at the end of all of the gradual reduction excerpts, in the second section of the gradual addition in the Debussy excerpt, and after the sudden reduction in Holst's "Uranus." The harp was likely scored in these contexts to highlight the thinness of the orchestral sound. The timpani also figured prominently in reduced textures: at the beginning of the gradual addition in Mahler's Symphony 1 and Sibelius's Symphony 1, at the end of the gradual reduction in Mahler's Symphony 2, in the suspenseful section before the moment of sudden addition in Strauss's *Tod und Verklarung*, and in the desolate section after the sudden reduction in Bruckner's Symphony 8. The timpani provided a pedal point or ostinato in these instances, which may have reinforced the striking effect of the sparse scoring. In future work, I plan on investigating the expressive role of local-level instrumentation and the reasoning behind these compositional choices.

The proposed four types of large-scale gestures constitute a starting point for inquiry in the pursuit of a theory of orchestral gestures. Further exploration of the orchestral repertoire will reveal other types of orchestral gestures, particularly on a local level. In future work, I will investigate the role of gestural troping, in which expressive meanings emerge from the interaction of opposing associations or forces (Hatten 2004). One potential example of this process is described by Rimsky-Korsakov ([1912] 1964): "The operation … consists in contrasting the resonance of two different groups … While the first group effects the *crescendo* gradually, the second group enters *piano* or *pianissimo*, and attains its crescendo more rapidly. The whole process is thereby rendered more tense as the timbre changes" (109). Additionally, analysis of orchestral gestures may discover instances where certain musical features do not coordinate with other orchestral gesture processes. These new expressive meanings have yet to be uncovered.

The analyzed examples in this study were specifically chosen to be played as musical stimuli in a perceptual experiment (reported in a companion paper).[23] As a result, I selected excerpts that convey only one overarching gesture and span a reasonable duration of time in order to provide a

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[23] (Goodchild, Wild, and McAdams 2016) [Chapter 3]

meaningful musical context for listeners. In the repertoire, many of the orchestral gestures are not as clearly demarcated as those discussed here. There are many examples where gestural shaping begins, but the processes are abandoned. Additionally, two types of gestures may merge, such as a gradual addition that leads directly into a gradual reduction (or vice versa). Therefore, further research is needed to explore the various contexts in which these gestures occur and how they coalesce or divert course to create other expressive meanings.

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CHAPTER 3

TOWARD A PERCEPTUALLY BASED THEORY OF ORCHESTRAL GESTURES

Recent studies have found that listeners experience strong emotions in response to dramatic changes in instrumental texture. However, there are few theories related to orchestration that would assist in interpreting these empirical findings. In Chapter 2, I proposed four types of large-scale orchestral gestures and analyzed twelve excerpts to uncover gestural meanings. Chapter 3 explores listeners' emotional responses to the four gestural types. This chapter reports the results of a listening experiment in which listeners continuously rated emotional intensity in response to the twelve excerpts. A visualization tool is used to explore the emotional responses and time varying musical parameters. The aim of the work is to contribute to a theory of orchestral gestures grounded in perceptual testing.

This chapter is based on the following research article:

Goodchild, M., Wild, J., and S. McAdams. "Toward a Perceptually Based Theory of Orchestral Gestures." Manuscript prepared for submission.

ABSTRACT

Research on emotional responses to music indicates that prominent changes in instrumentation and timbre elicit strong responses in listeners. Although orchestration treatises allude to textural changes for structural and expressive purposes, a clear taxonomy of techniques and a conceptual framework related to how they function are lacking. This paper investigates listeners' experiences to four types of orchestral gestures—large-scale timbral and textural changes that occur in a coordinated, goal-directed manner—through an exploratory experiment that collected continuous responses of emotional intensity for musician and nonmusician listeners. The results suggest that the response profiles differ for the four gestural types, indicating the distinct expressive shaping of orchestral gestures. We also demonstrate the importance of a visualization tool that compiles the emotional intensity ratings with score-based and performance-based musical features for qualitative and quantitative analysis.

INTRODUCTION

Orchestration—the art of structuring music with timbre—became a fundamental aspect of musical composition in the nineteenth century. Romantic composers increasingly used orchestral texture as both a structural and expressive device, essential to the conception of a composition (Todd 1986). The shaping of instrumentation has the capacity to demarcate formal divisions, to provide broad contrasts of weight and colour, and to supply expression and emotional content. As McAdams (2013) states:

> Larger-scale changes in timbre can … contribute to the expression of higher-level structural functions in music … Orchestration can play a major role in addition to pitch and rhythmic patterns in the structuring of musical tension and relaxation schemas that are an important component of the aesthetic response to musical form (60).

Despite the evident integral function of timbre on the listening experience, a disparity exists between the importance of orchestration on the one hand and the amount of scholarly attention paid to the subject on the other. This imbalance is even more apparent when considering recent findings in music and emotion research. Empirical studies have reported that changes in instrumentation and texture induce strong emotional responses in listeners. For example, Guhn, Hamm, and Zentner (2007) conducted a study that attempted to link distinct subjective experiences and specific physiological changes. In their analyses of Romantic musical excerpts where chills (i.e., *frisson*) were experienced in coordination with distinct patterns of heart rate and skin conductance, they found that the musical passages were marked by particular dynamic, harmonic, and structural characteristics. Among these musical features, passages featuring the contrast of a solo instrument and the orchestra induced strong emotional responses. In his study of survey responses based on self-reports, Sloboda (1991) reported ten musical features directly associated with emotional responses. Similar to the findings of Guhn et al., Sloboda found that a sudden dynamic or textural change was associated with specific physical reactions, such as chills, tears, and an increase in heart rate. Along these lines, Panksepp (1995) suggested that listeners experience strong emotional responses, such as chills, when there is a striking reduction of instrumental forces (e.g., a solo instrument emerging out of the orchestra) or a dramatic, goal-directed crescendo. Although these studies have made significant steps towards investigating the links between music and emotion, the analyses rarely consider the musical features beyond the immediate context. The findings from music and emotion research suggest that texture and instrumentation profoundly affect the listening experience, but a lacuna exists in the field of music theory related to orchestration. Critical evaluations of orchestration theory indicate that it has lagged behind and never reached the depth or precision of other musical fields (Boulez 1987; Sandell 1995; Slawson 1985). The lack of theory or guiding principles leaves the orchestrator and theorist with a limited explicit understanding of these processes.

Types of orchestral gestures

As a starting point for inquiry, Goodchild proposed a typology of orchestral gestures based on large-scale timbral and textural changes.[1] As shown in a visual representation in Figure 3-1, the four types are defined by changes in instrumentation, organized into a two-by-two design based on time course (gradual or sudden changes) and direction (additive or reductive changes). The x-axis represents time and the y-axis represents the number of instrumental parts that are engaged.[2] Each gesture adds or removes instruments, gradually or suddenly, as a coordinated change over time. The four types relate to descriptions from orchestration treatises of an “orchestral crescendo” (gradual addition), the reverse process (gradual reduction), and timbral contrasts including a rapid switch to tutti forces (sudden addition) and the drop-off to a contrast choir or soloist (sudden reduction). Goodchild characterizes large-scale orchestral shaping as gestures, representing their goal-directed

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[1] (Goodchild 2016a) [Chapter 2]

[2] See discussion of the texture parameter below.

sense of motion and their structural and expressive role in the musical discourse. The dramatic shaping of the orchestral gestures coordinates disparate musical elements (e.g., instrumental texture, dynamics, tempo and other musical parameters), creating a sense of agency and emotional force.

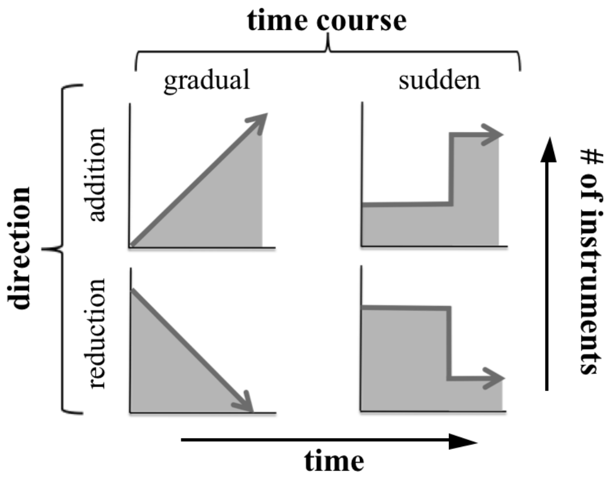

Figure 3-1. Four types of orchestral gestures

Aims

In this exploratory behavioural experiment, we tested the perceptual effect of orchestral gestures through continuous ratings of emotional intensity and retrospective ratings. We employed two approaches to investigate how emotional responses to large-scale orchestral gestures unfold in time in relation to various musical features. First, a time series regression study will attempt to predict changes in emotional response by modeling changes in various musical features (such as instrumental texture, loudness, and tempo). Second, we advance a new type of visualization that illustrates both the relative textural density of each instrumental family over time and maps musical-feature overlays of time-varying musical parameters and the emotional intensity ratings.

A multitude of factors, including moods, preferences, and familiarity with musical stimuli, may influence an individual's affective responses to music (Vuoskoski 2012). Therefore, we collected retrospective ratings in order to account for these moderating factors. To complement the continuous ratings, participants also reported the number of experienced chills, defined as goose bumps, shivers, or tingles down the spine. Although rare, chills provide insight into strong emotional experiences, which are powerful, salient, and memorable (Whaley, Sloboda, and Gabrielsson 2009).

This interdisciplinary study benefits from a reciprocal exchange of the fields of music theory and experimental psychology, specifically through perceptual testing of music-theoretical hypotheses and through the use of analytical insights to explain emotional responses to music. The first aim is to investigate one aspect of the temporal dynamics of the listening experience by researching the musical features in orchestral music that elicit emotional responses. We also aim to contribute to the development of a theory of orchestral gestures through music-theoretical analyses and results from the perceptual experiment.

Experimental hypotheses

To our knowledge, this study is among the first to isolate various textural and timbral changes in relation to musical structure and to explore their potential affective responses. The literature presents inconclusive predictions for listeners' emotional responses to orchestral gestures. Schubert (2004) suggests that there is a causal relationship between combinations of musical features and emotional response. In his regression study, Schubert reported that between 35% and 73% of the variation in perceived arousal could be explained mainly by loudness and tempo, but there were inconsistent associations for texture and timbre. Gabrielsson and Lindström (2010) suggest that a predictable relationship exists between parameters of loudness and timbre on the one hand and emotional intensity on the other; listeners reported that higher degrees of loudness and upper harmonics were associated with emotions of higher intensity. Several studies have reported connections between chill responses and sudden or unexpected changes in texture and loudness (Guhn, Hamm, and Zentner 2007; Sloboda 1991; Grewe, Nagel, Kopiez, and Altenmuller 2007). In particular, one of the most common acoustical correlates of chills is a rapid increase in loudness (Huron and Margulis 2010). In addition to a gradual crescendo, Panksepp (1995) proposed that a sudden reduction in texture (e.g., a solo instrument emerging out of the orchestra) induces a strong emotional response, such as a chill, because the textural change mimics feelings of social loss.

Given these experimental results, we expected that listeners would have strong emotional responses to the orchestral gestures under investigation, but their nature and extent is unknown. We predicted that listeners would experience more chills to the sudden gestures than gradual ones. We also expected that the additive gestures would have higher emotional intensity on average compared to reductive gestures. Additionally, emotional intensity ratings would likely have more variability in the rating profiles for the sudden gestures compared to gradual ones.

METHODS

Participants

We recruited 45 participants (22 musicians and 23 nonmusicians) from the Montreal area via McGill University email lists and classified advertisements. The musician listeners (11 females) had an average age of 24 years (SD = 5.7) and had studied a minimum of 2 years in an undergraduate degree in music. The nonmusician listeners (12 females) had an average age of 24 years (SD = 10.3) and had less than 2 years of musical training in early childhood. Musician and nonmusician listeners were included in order to assess the role of musical expertise on listening experience. All participants were pre-screened to ensure normal hearing and a history of strong emotional responses to music (Whaley, Sloboda, and Gabrielsson 2009).

Stimuli

Twelve musical excerpts were chosen to fit within the four types of gestures (three excerpts per type), as shown in Table 3-1. The musical passages are categorized by only one overarching orchestral gesture (as described above) and were drawn from the symphonic repertoire of the late nineteenth and early twentieth centuries, where large-scale gestures were likely to occur. The excerpts were 1 to 3 minutes in duration in order to provide a listening context. Well-known excerpts were avoided to minimize the possibility that participants would respond to personal or external associations (such as episodic memory and evaluative conditioning mechanisms) (Juslin and Västfjäll 2008). All excerpts were extracted from commercial CD recordings in uncompressed waveform audio file format (WAV) at 44.1 kHz with 16-bit amplitude resolution. The recordings were chosen qualitatively for power of expression and the use of similar recording techniques. A two-second fade-in or fade-out was added with Audacity (Audacity Team, audacityteam.org) if the excerpt did not begin or end with silence, respectively.

The stimuli were stored on a Mac Pro computer (Apple Computer, Inc., Cupertino, CA), amplified through a Grace Design m904 monitor (Grace Design, Boulder, CO), and presented over Dynaudio BM6a loudspeakers (Dynaudio International GmbH, Rosengarten, Germany). In separate pilot experiments, the level of each excerpt was set to match a concert experience, such that the excerpts were not too loud or soft, keeping in mind the relative dynamic level of the score. Sound levels for each excerpt were measured with a Brüel & Kjær Type 2205 sound-level meter (A-weighting) placed at the level of the listener's ears in the front and rear rows, with maximum values ranging between 81.6 and 97.0 dB (mean = 91.4, SD = 3.9).

Table 3-1. List of stimuli by gesture type, excerpt number (number) and Appendix number for visualization (A+number), composer, piece, measure numbers (mm.), recording information, and duration (min:s).

Type	#	Composer	Piece	mm.	Recording	Duration
Gradual Addition	E01 A1	Gustav Mahler	Symphony 1, III (1888)	1-32	New York Philharmonic, conducted by Leonard Bernstein, Sony Classical, 2001	1:50
	E02 A2	Gustav Mahler	Symphony 2, I (1894)	254-302	New York Philharmonic, conducted by Leonard Bernstein, Sony Classical, 2001	2:28
	E03 A3	Jean Sibelius	Symphony 1, I (1900)	1-96	Lahti Symphony Orchestra, conducted by Osmo Vanska, BIS, 1995	2:53
Gradual Reduction	E04 A4	Modest Mussorgsky/ Maurice Ravel	*Pictures at an Exhibition*, "Bydlo" ([1874] 1922)	39-64	Berliner Philharmoniker, conducted by Herbert von Karajan, Deutsche Grammophon, 1964	1:59
	E05 A5	Gustav Mahler	Symphony 2, I (1894)	80-116	New York Philharmonic, conducted by Leonard Bernstein, Sony Classical, 2001	2:03
	E06 A6	Richard Strauss	*Ein Heldenleben,* III (1898)	331-353	London Symphony Orchestra, conducted by Sir John Barbirolli, EMI Classics, 1996	2:09
Sudden Addition	E07 A7	Ralph Vaughan Williams	*London Symphony*, I (1914)	8-53	Royal Liverpool Philharmonic Orchestra, conducted by Vernon Handley, EMI Classics, 2011	2:42
	E08 A8	Richard Strauss	*Tod und Verklärung,* II (1889)	360-395	London Symphony Orchestra, conducted by Jascha Horenstein, Chandos Records, 1987	1:35
	E09 A9	Claude Debussy	*La Mer*, I (1905)	122-141	Berliner Philharmoniker, conducted by Simon Rattle, EMI Classics, 2005	2:02
Sudden Reduction	E10 A10	Gustav Holst	*The Planets*, "Uranus" (1916)	193-236	London Philharmonic, conducted by Sir Adrian Boult, EMI Classics, 2002	1:19
	E11 A11	Anton Bruckner	Symphony 8, I (1890)	221-270	Wiener Philharmoniker, conducted by Pierre Boulez, Deutsche Grammophon, 2000	1:40
	E12 A12	Antonín Dvořák	Symphony 9, I (1893)	200-286	Houston Symphony, conducted by Christoph Eschenbach, EMI Records/Virgin Classics, 2000	1:26

Procedure

The experimental sessions took place at the Music Perception and Cognition Lab at the Schulich School of Music of McGill University. Six group-listening sessions were held to represent a concert experience. In each session, a maximum of eight participants listened in a dimmed room with acoustic absorbing material on the walls at a comfortable temperature (22°C). On arrival participants were randomly assigned a seat within three rows of five chairs facing the two loudspeakers arranged at ±45° (see Figure 3-2 for seating arrangement). An empty chair between participants reduced distraction and allowed the placement of the questionnaire and slider (described below) when not in use. Only two participants were seated in the front row in order to reduce the proximity to the speakers and to limit the decibel differential between the front and back rows.

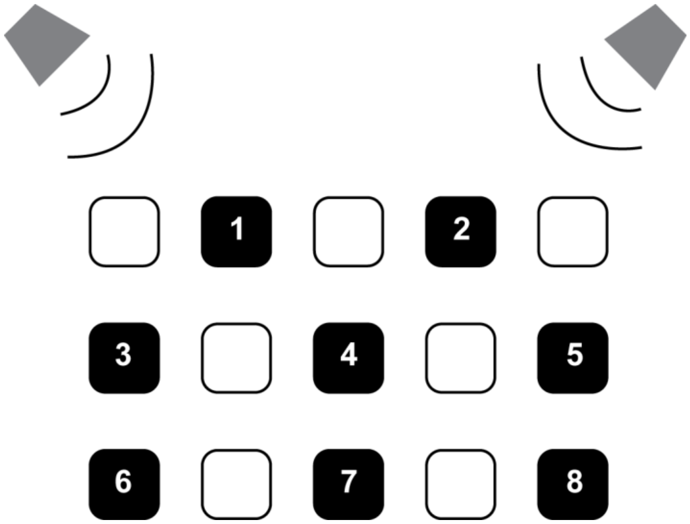

Figure 3-2. Seating arrangement for experiment. Black squares indicate chairs used. White squares indicate empty chairs. Grey quadrangles represent speaker placement and orientation.

Participants were asked to sign an informed-consent form and read the instructions on a clipboard. The first part of the experiment consisted of two practice trials, which allowed participants to ask questions and to familiarize themselves with the experimental procedure. The two practice pieces consisted of a gradual addition excerpt from Scriabin's Symphony 1, movement III, and a sudden reduction excerpt from "Great Gate of Kiev" from *Pictures at an Exhibition* by Mussorgsky/Ravel. Participants were told that the practice pieces were representative of the music they would hear in the main experiment. The data from the practice stage were not analyzed. The main experiment consisted of the 12 stimuli (listed in Table 3-1 above) played in a randomized order for each session. The experimental session lasted approximately one hour, and the listeners were paid $15 for their participation.

While listening to each excerpt, the participants used a handheld slider to continuously rate emotional intensity that they felt in response to the music. They were instructed to rate the strength of their emotional response regardless of whether it was a positive or negative feeling. They were told that the slider position should reflect a personal reaction to the music and not what they imagine the music is trying to expresses (e.g., if the music sounded intensely jubilant, but the participant felt only a mild response, they would rate low emotional intensity on the slider). In the dimensional model of emotion, all emotions are understood as varying degrees of two independent neurophysiological systems related to arousal (low to high) and valence (negative to positive) (Russell 1980; Eerola and Vuoskoski 2013; Schubert 2004). Following previous work in the field, the unidimensional emotional intensity scale would seem to tap into arousal or activation of emotion, rather than the valence component (McAdams et al. 2004; Schubert 2010). Given the exploratory nature of the experiment, we were interested in the evolution of emotional intensity over time and its connection to the musical features that sculpt the orchestral gestures.

Apparatus

Slider

Recent technological advances have allowed researchers to track over time perceptual and emotional responses, including aesthetic judgments, tension, arousal and valence, and emotional force and familiarity/resemblance. A number of continuous rating devices have been developed, such as spring-loaded tongs (Nielsen 1983), the continuous response digital interface (CRDI) dial (Madsen and Fredrickson 1993), a virtual slider or emotion space manipulated by a mouse (Farbood 2012; Schubert 2004), and a handheld mechanical slider box (McAdams et al. 2004). The method has been used successfully; the task is intuitive and does not require musical expertise (Schubert 2004).

We added an elastic band inside the slider box in order to provide force feedback through physical resistance. As the slider was moved in the direction of more emotional intensity, the participant increasingly felt more resistance to the movement. In pilot studies, participants reported that the force feedback on the slider was an intuitive method of rating that obviates the need for visual attention to the device. Participants held the slider box on their lap and moved the slider forward and backward to indicate higher and lower emotional intensity, respectively. They began each trial with the slider at the bottom (low emotional intensity) and were told that the maximum intensity point at the "strong" end of the scale, where the slider can be pushed no further, should correspond to the strongest emotional response to orchestral music they have experienced. This anchoring was chosen to ensure that participants used the majority of the range of the slider while preventing them from overuse of the maximum end, thereby creating a flat line of the signal and data loss.

Questionnaires

Before and after the experimental session, participants completed the International Positive and Negative Affect Schedule Short Form (I-PANAS-SF), with the five positive affects (alert, inspired, determined, attentive, and active) and five negative affects (upset, hostile, ashamed, nervous, and afraid) (Thompson 2007). The responses were changed from a general question of mood ("Thinking about yourself and how you normally feel, to what extent do you generally feel…") to a question of their current mood-state ("To what extent do you currently feel…"). The interval measure on a 5-point Likert scale was adjusted from "never — always" to "very low — very strong."

After each excerpt, participants completed retrospective questionnaires outlining their specific subjective experiences. Participants rated their familiarity ("Did you know this excerpt?")

and their preference ("Did you like this excerpt?") on a seven-point scale from 1 representing "not at all" to 7 representing "extremely." They were also asked about specific physical reactions, such as the experienced number of chills.[3]

After the main experiment concluded, participants completed a final questionnaire outlining their musical training, listening habits and preferences, socio-demographic characteristics, personality, and their experience using the slider.

Data analysis

Emotional intensity slider responses

The computer interface was programmed with PsiExp computer environment (Smith 1995). Slider responses were measured simultaneously using a MIDI-based acquisition hardware, which converted the slider position to a 7-bit value and sent MIDI timings to the controlling computer (maximum response latency of 10 msec) (Fléty 2002). The data processing was conducted in MATLAB (Mathworks, Inc). The emotional-intensity slider data were resampled at 2 Hz.[4] Due to the force exerted by the elastic band when stretched at maximum, a block was inserted into the slider, resulting in half the scale of MIDI ratings between 54 and 127. The data were normalized to a range between 0 and 1 for each participant across all excerpts. Due to our interest in the between-excerpts variation, normalization reduces the inter-participant variability due to different ranges of rating. The slider ratings were averaged to create separate time series for musician and nonmusician

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[3] The questionnaire also included questions about several other subjective experiences, but will not be reported here due to the scope of the paper. Participants were asked if they experienced physical reactions including tears, sense of awe, and action tendencies (i.e., urges to move to the music). In addition, a randomized order of emotional models was used, which included the Geneva Emotional Scale (GEMS-9) (Zentner, Grandjean, and Scherer 2008), the 3-dimensional model (Schimmack and Grob 2000), and the basic emotion model (Ekman 1999). Participants were instructed to rate the intensity of their emotional responses to the excerpt for each emotion term, rated on a seven-point scale from 1 representing "not at all" to 7 representing "extremely."

[4] The data were resampled using MATLAB's interpolation function called "interp1" using the nearest neighbour method. This sampling rate was selected based on the data of the musical feature variables to be included (see below). It provided a compromise between downsampling the loudness and spectral centroid parameters and upsampling the tempo parameter. In Schubert's (1999) study, he sampled at 1 Hz and he proposed that sampling more than twice a second is redundant.

groups. Mean ratings provide a measure of central tendency over time for each listener group. The variability of emotional intensity ratings across listeners is discussed further below.

Musical features

Musical features were coded as time series to be included in the regression analysis and in the visualizations. Three performance-based features (loudness, spectral centroid, and tempo) and three score-based features (instrumental texture, onset density, and contour) were selected due to their importance in descriptions of orchestral gestures in treatises and in similar research (described further below) (Adler 2002; Schubert 2004).[5] Loudness and spectral centroid were extracted from the commercial recordings with PsySound3 (Cabrera, Ferguson, and Schubert 2007). Using the auditory filter model by Moore, Glasberg, and Baer (1997), the loudness of steady-state sounds was calculated in sones, calibrated to the measured sound pressure level in dB of each excerpt in the room. Loudness, therefore, provides a measure of the changes in dynamics during the course of the excerpt. Spectral centroid has a robust connection to perceived brightness.[6] Extracted in Hz (frequency), spectral centroid measures the center of gravity of the relative weights of the frequencies present in the signal.

Tempo, texture, onset density, and contour were manually coded. Using Sonic Visualiser (Cannam, Landone, and Sandler 2010), the inter-onset interval (IOI) between beats was marked by the first author, independently verified by a musician colleague, and then converted into time series in beats per minute (bpm).[7] Automated methods of beat extraction were unsuccessful due to the textural density of the orchestral sound files.

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[5] Schubert (2004) included tempo, spectral centroid, loudness, melody, and texture in his study.

[6] For a review see, McAdams (2013).

[7] The formula can be understood as: bpm = $60 \cdot (\frac{1}{IOI})$ where IOI is first calculated as onset time$_{n+1}$ – onset time$_n$ in seconds. If there were not any instruments with an attack on a particular beat, the timing was interpolated based on the surrounding context.

Following Emery Schubert's (2004) approach, texture was objectively coded as the number of independent voices (or parts) sounding at each beat. An instrument that doubles the same pitch of another player of the same instrument was omitted from the count (e.g., flutes 1 and 2 on the same pitch would count as one voice, but a flute and oboe on the same pitch would count as two voices). If one instrument produces two or more notes, each is counted (e.g., violin with triple stops counts as three voices). Notes that are attacked on a previous beat and sustained into the beat under evaluation are included in the count.

In addition to a total sum of all instruments, the texture parameter was expanded to include information about the contributions of each instrumental family (strings, woodwinds, brass, and percussion), as well as the organ and harp. The texture parameter is displayed as a stacked bar graph with the instrument family indicated by colour. With this approach, one can view the textural density of each family and its evolution over time.

The onset density counts the number of onsets or attacks per beat, following the same procedure as the texture parameter; however, the third rule involving sustained notes is omitted. Onset density distinguishes between sustained pitches or long note values (low onset density) and short note values or rapid figuration (high onset density) in sections that may have the same count for instrumental texture.

The contour variable tracks the highest and lowest notated pitches, also known as the *ambitus*, at every beat. The range spans from C_1 to C_8.[8]

All of the musical feature time series were resampled at 2 Hz (as described above). For the regression study, all of the features and slider data were filtered to smooth the high-frequency noise.[9] For the visualizations, onset density, and contour were not smoothed due to the discrete nature of these values. For all of the excerpts, the first two seconds of data were cut, except for excerpt 3 in

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[8] Schubert (2004) calculated the main contour of the melody (not the upper and lower ambitus).

[9] A low-pass digital filter (4th-order phaseless Butterworth) with a cutoff frequency at 0.2 Hz was used.

which the first five seconds were cut. The cut was due to fact that the beginnings of the recordings have only a few instruments playing, which created a spurious high spectral centroid from the background noise of the recording. Two to five seconds was deemed to be an acceptable data loss, especially given the initial orientation time, a period of acclimatization during which time the responses are unreliable, of a minimum of 2 seconds (median of 8 seconds) (Schubert 2012).

RESULTS

Retrospective ratings

Mood-state questionnaire

A nonparametric Wilcoxon signed-rank test was used to determine if there were any significant differences in the responses to the I-PANAS-SF mood questionnaire before and after the experiment. The values for each category of positive and negative affect were summed for each participant. No statistically significant median differences were found at the end of the experiment compared to the beginning for both positive [$Z = -1.4$, $p = .16$, $r = -.03$] and negative [$Z = -1.9$, $p = .06$, $r = -.04$] affect ratings.[10] This result indicates that participants' moods were not significantly affected by the experimental procedure.

Apparatus questions

Participants were asked about the ease of use of the slider on a seven-point scale (1 = very difficult, 7 = very easy). The ratings were high overall, with a median of 6.0 (range = 5.0).[11] For the question regarding the influence of using the slider on the listening experience (1 = distracting, 7 =

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[10] For the negative affect ratings, 18 participants did not change, 18 had negative differences (rated negative affect less strongly) and 9 had positive differences (rated negative affect more strongly). For the positive affect ratings, four participants did not change, 19 had positive differences (rated positive affect more strongly) and 22 had negative differences (rated positive affect less strongly).

[11] The median, range and interquartile range are used when assumptions of normality were not met using parametric statistics. They involve fewer assumptions about the data distribution and are less susceptible to outliers compared to the mean and standard deviation.

improved focus), the ratings were moderate (neutral), with a median of 4 (range = 6.0). These results suggest that the slider was not difficult to use and did not impede the listening experience too strongly.

Familiarity

The familiarity scores as recorded on a seven-point scale were low overall, with a median across all excerpts of 1 (range = 6.0). For each participant, a median score was calculated across the gesture types. A nonparametric Friedman test compared median ratings of familiarity among the four experimental conditions and a significant difference was found, $\chi^2(3) = 10.1$, $p = .02$. The post-hoc Wilcoxon signed-rank test with Bonferroni adjustment for multiple comparisons revealed no significant differences among the types.

A nonparametric Mann-Whitney U test was run to determine if there were differences in median familiarity ratings between the musicians and nonmusicians for each excerpt. Table 3-2 reports the results along with the median and range. Compared to the nonmusicians, musicians were more familiar with E04 (Mussorgsky/Ravel's "Bydlo" from *Pictures at an Exhibition*), E05 (Mahler's Symphony 2, I), E09 (Debussy's *La Mer,* I), and E12 (Dvořák's Symphony 9, I).

Table 3-2. Median and range for familiarity ratings by musicians, nonmusicians and all participants; Mann-Whitney U statistic comparing differences in training, effect size *(r)*, and p-value with Bonferroni correction (* $p < .004$).

		Familiarity Ratings											
		E01	E02	E03	E04	E05	E06	E07	E08	E09	E10	E11	E12
Musician	Mdn	5.0	1.0	1.0	2.0	2.0	1.0	1.0	1.0	4.0	1.0	1.0	5.0
	Range	6.0	6.0	6.0	6.0	6.0	6.0	5.0	3.0	6.0	6.0	3.0	6.0
Nonmusician	Mdn	3.5	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
	Range	6.0	3.0	4.0	5.0	1.0	3.0	5.0	5.0	3.0	4.0	2.0	3.0
All	Mdn	5.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	2.0
	Range	6.0	6.0	6.0	6.0	6.0	6.0	5.0	5.0	6.0	6.0	3.0	6.0
Mann-Whitney	U	179	197	207	139	141	216	235	233	136	214	231	93
	r	–.26	–.23	–.18	–.43	–.45	–.16	–.08	–.09	–.46	–.18	–.11	–.56
	p	.08	.12	.23	**.004***	**.002***	.29	.60	.56	**.002***	.23	.45	**.001***

Preference

The preference scores as recorded on a seven-point scale were moderate overall, with a median across all excerpts of 4.0 (range = 6.0). For each participant, a median score was calculated across the gesture types. A nonparametric Friedman test compared median ratings of preference among the four experimental conditions. No significant differences were found, $\chi^2(3) = 5.55$, $p = .14$.

Table 3-3 lists the median and range of the preference scores for musicians, nonmusicians, and all participants across excerpts. A Mann-Whitney U test was run to determine if there were differences in preference ratings between musicians and nonmusicians. No statistically significant differences in ratings were found.

Table 3-3. Median and range for preference ratings by musicians, nonmusicians and all participants; Mann-Whitney U statistic comparing differences in training, effect size *(r),* and p-value with Bonferroni correction (* *p* < .004).

		Preference Ratings											
		E01	E02	E03	E04	E05	E06	E07	E08	E09	E10	E11	E12
Musician	Mdn	4.0	4.0	5.0	4.0	5.0	5.0	5.0	4.0	5.0	5.0	4.0	5.0
	Range	5.0	6.0	5.0	6.0	6.0	6.0	6.0	6.0	4.0	6.0	6.0	6.0
Non-Musician	Mdn	5.0	4.5	4.0	4.0	4.0	4.0	5.0	3.5	5.0	2.0	3.5	4.5
	Range	5.0	7.0	5.0	5.0	6.0	5.0	6.0	6.0	5.0	6.0	5.0	6.0
All	Mdn	5.0	4.0	4.0	4.0	4.0	4.0	5.0	4.0	5.0	4.0	4.0	5.0
	Range	5.0	7.0	5.0	7.0	6.0	7.0	6.0	7.0	5.0	6.0	6.0	7.0
Mann-Whitney	*U*	217	193	176	175	164	203	213	189	187	94	185	183
	r	–.12	–.14	–.27	–.24	–.31	–.18	–.14	–.16	–.23	–.55	–.24	–.21
	p	.40	.34	.07	.11	.04	.24	.35	.29	.12	.001	.11	.15

Chills

As shown in the histogram in Figure 3-3, there was a wide range of responses for the number of reported chills. Participants experienced between 0 and 18 chills across the entire experiment, with a median across all excerpts of 3 (range = 18). Sixteen participants (35.5%) did not report any chills, indicating that roughly two-thirds of the participants experienced at least one chill response.

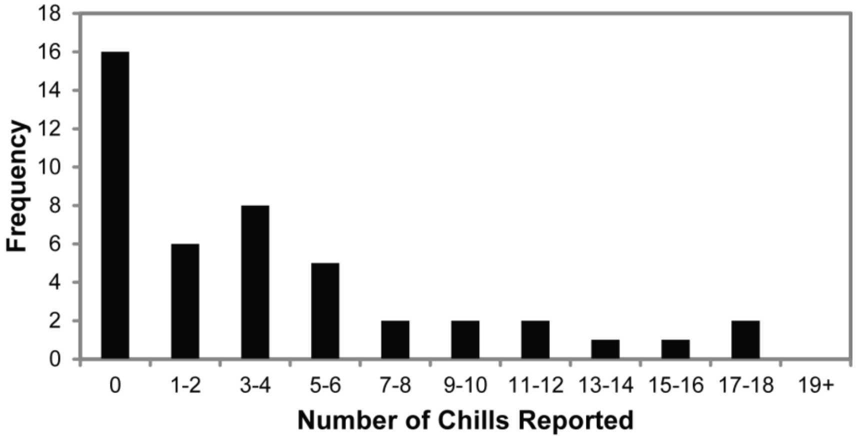

Figure 3-3. Histogram of the number of chills reported during the experiment

Table 3-4 lists the median and range of the number of chills reported for musicians, nonmusicians, and all participants across excerpts. A Friedman test compared the median number of reported chills among the four experimental conditions and a statistically significant difference was found, $\chi^2(3) = 22.1, p < .001$. The post-hoc Wilcoxon signed rank test with a Bonferroni adjustment revealed that the sudden addition type had significantly more chills reported compared to the gradual reduction ($Z = –3.2, p = .001$), sudden reduction ($Z = –2.8, p = .006$), and gradual addition ($Z = –2.5, p = .01$). There were no significant differences among the other gestural types.

As shown in Table 3-4, a Mann-Whitney U test was run to determine if there were differences in the number of reported chills between musicians and nonmusicians. No statistically significant differences were found.

Table 3-4. Median and range for the number of chills reported by musicians, nonmusicians and all participants; Mann-Whitney U statistic comparing differences in training, effect size *(r),* and p-value with Bonferroni correction (* *p* < .004).

		Number of Chills											
		E01	E02	E03	E04	E05	E06	E07	E08	E09	E10	E11	E12
Musician	Mdn	0	0	0	0	0	0	0	0	1	0	0	0
	Range	2	3	3	1	1	4	3	1	4	3	3	5
Non-Musician	Mdn	0	0	0	0	0	0	0	0	0	0	0	0
	Range	3	3	4	3	1	1	3	3	4	1	2	5
All	Mdn	0	0	0	0	0	0	0	0	1	0	0	0
	Range	3	3	4	3	1	4	3	3	4	3	3	5
Mann-Whitney	*U*	230	218	248	244.5	221	231	240	227	179	242	220	252
	r	-.16	-.17	-.02	-.05	-.17	-.13	-.05	-.15	-.27	-.06	-.18	-.01
	p	.28	.26	.87	.72	.25	.40	.72	.32	.07	.69	.24	.95

Emotional intensity ratings

Median

Medians were calculated from the normalized continuous rating data for each participant for each of the 12 excerpts. A grand mean value for each category for each participant was then calculated. A mixed-design ANOVA was performed to determine whether repeated-measures orchestral gesture parameters of time course (addition vs. reduction) and direction (addition vs. reduction), as well as the between-subjects factor of musical training, had an effect on participants' median emotional intensity ratings.[12] In addition to a significant main effect of direction, $F(1, 43) = 22.0$, $p = .001$, $\eta_p^2 = 0.29$, a significant three-way interaction was found, $F(1, 43) = 5.80$, $p = .01$, $\eta_p^2 = 0.14$. To determine the nature of the interaction, two tests of simple interactions were performed on the ratings of the musicians and nonmusicians separately, with time course and direction as repeated-measures factors. A significant main effect of direction was found for the musicians, $F(1,22) = 13.7$, $p = .001$, $\eta_p^2 = 0.38$, and nonmusicians, $F(1,21) = 6.17$, $p = .02$, $\eta_p^2 = 0.23$. Post-hoc analysis with a Bonferroni adjustment revealed that the median ratings for the reduction type ($M =$

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[12] All of the assumptions of normality for the ANOVA were met. There were no outliers in the data, as assessed by inspection of a boxplot for values greater than 1.5 box-lengths from the edge of the box. Median ratings were normally distributed, as assessed by Shapiro-Wilk's test ($p > .05$).

0.50) were significantly higher than the addition type (*M* = 0.41), *p* = .001 for the musicians. Similarly, the same tests for the nonmusicians revealed that the median ratings for the reduction type (*M* = 0.48) were significantly higher than the addition type (*M* = 0.39), *p* = .02.

A visual representation was used to investigate the three-way interaction in the mixed-design ANOVA using the means and a 95% confidence interval (Figure 3-4). Given that the main effects of direction (additive and reductive) were preserved for both musicians and nonmusicians in the tests of simple interactions, the interaction appears to be modulated by a difference in ratings between the musicians and nonmusicians for the time course (gradual and sudden): musicians rated gradual reductive excerpts higher than gradual additive excerpts, whereas nonmusicians rated sudden reductive higher than sudden additive.

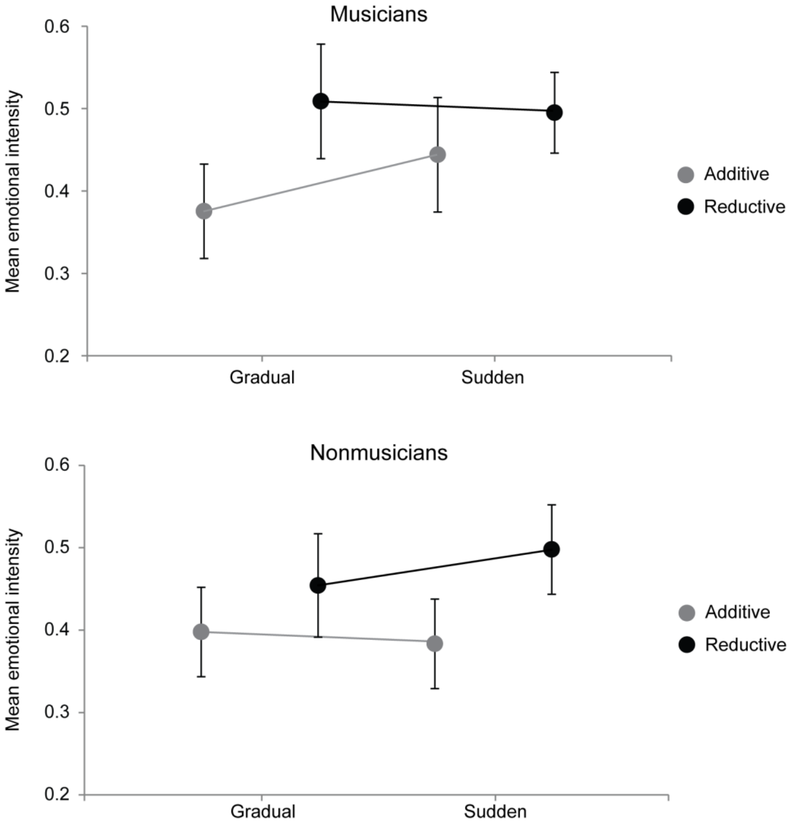

Figure 3-4. Grand mean emotional intensity ratings with 95% confidence intervals for musicians and nonmusicians.

Interquartile range

In order to investigate the variability of ratings, we calculated the interquartile range—the difference between the third and first quartiles as a measure of statistical dispersion—for each participant for each of the 12 excerpts. A grand mean value for each category was then calculated. A mixed-design ANOVA was performed to determine whether time course (gradual and sudden), direction (addition and reduction), and musical training had an effect on the variability of emotional intensity ratings. A significant main effect of direction was found, $F(1, 43) = 27.7, p = .001, \eta_p^2 = 0.39$. Post-hoc analysis with a Bonferroni adjustment revealed that the variability for the additive type ($M = 0.27$) was significantly higher than the reduction type ($M = 0.20$), $p = .001$. No significant effect of training was found, indicating that the variability of the musicians' and nonmusicians' ratings were similar. Furthermore, the effect of time course was not significant, suggesting that the variability was not different between gradual and sudden gestures.

Time series regression study

Given the difficulty in interpreting a single measure of central tendency of a time-varying behavioural measure, we turned to other analytical approaches that consider the temporal dynamics of emotional responses and musical features. Continuous response procedures pose considerable methodological issues, particularly the use of statistical analyses for data interpretation. One major obstacle is that the assumption of independent samples is violated with time series data. Another is that the participants do not respond immediately to a stimulus, which creates a delay in response that must be factored into the analysis as well. To address these issues, Schubert (1999; 2004) proposed a quantitative modeling procedure, which involves the ordinary least squares approach to linear regression and takes into account response delay and serial correlation. Following the procedure outlined by Schubert, we conducted two linear regression models of the musicians' and nonmusicians' emotional responses. Based on the analyses in the companion paper, one excerpt was chosen as the most representative example for each orchestral gesture type: excerpt 1 for gradual addition, excerpt 4 for gradual reduction, excerpt 7 for sudden addition, and excerpt 10 for sudden reduction.[13]

Four musical features (loudness, spectral centroid, tempo, and instrumental texture, as described above) were used as predictors of the emotional response ratings in the regression analysis.[14] We limited the number of predictors given that the likelihood of a type I error is increased with a greater number of variables included in the model.[15] These musical features were chosen based on their importance in Schubert's (2004) study.

In addition to the pre-processing described above related to the visualizations, all the data were normalized between 0 and 1 for each excerpt, because the changes in the signal (not the absolute values) are of interest in the regression analysis. To minimize serial correlation, we applied a first order difference transformation to all of the variables, which produces a gradient time series indicating the amount of change in the variable for each sample point.[16] To address response delays, we duplicated each musical feature variable at lags of 0, 1, 2, 3, and 4 seconds, thereby generating 20 different predictors (four variables at five lags).

We adapted Schubert's (1999) syntax in SPSS Statistics (IBM, Armonk, NY) to conduct a stepwise ordinary-least squares (OLS) regression in order to determine appropriate predictors. Next, the residual was diagnosed for serial correlation using an autocorrelation function. Given that all of the residuals were serially correlated, we conducted a first-order autoregressive adjustment (AR1)

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[13] (Goodchild 2016a) [Chapter 2].

[14] For the regression, the instrumental texture variable only included the total number of instruments and was not divided by instrumental family.

[15] A type I error in statistical testing is a "false positive"—incorrectly rejecting a true null hypothesis.

[16] A differencing adjustment involves subtracting each value in the time series from its preceding value.

that consists of a linear combination of the previous error terms.[17] Finally, we analyzed the residual of this combination to determine if the effects of serial correlation had been removed using the Durbin-Watson statistic and autocorrelation function.[18]

Table 3-5 reports the first-order autoregression models using a stepwise method for the emotional intensity ratings of the musicians and nonmusicians. All but one of the autoregressive models have significant coefficients, but only a small portion (from 1% to 17%) of the variance was explained. The one exception is the model for the nonmusicians' average response to E01 (gradual addition), which revealed no significant results for any of the features. Nearly all of the musical feature coefficients were positive, indicating changes in emotional intensity occur in the same direction as changes in the other variables; however, the model for nonmusicians in E10 (sudden reduction) revealed that loudness (lagged at 2 seconds) decreased as emotional intensity increased.

Based on the Durbin-Watson statistic and the autocorrelation function of the residuals for all of the models, the difference transformation and the autoregressive adjustment were not able to remove completely the effects of serial correlation. All of the autoregressive coefficients (AR1) were close to 1, which suggests that the emotional intensity ratings at a given moment were mainly determined by the preceding context, rather than changes in musical features.[19] Therefore, the validity of the models is compromised by the presence of serial correlation and the results should be interpreted with caution.

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[17] Schubert (2004) states "This term factors in a kind of memory that is implicit when dealing with time-series data. With conventional experimental designs, the assumption of independence might be satisfied by segmenting the music into small blocks, and testing each one separately, but this destroys the musical context. Autoregressive adjustment allows real pieces to be analyzed in a more realistic way because the effect of musical context or the 'emotional memory' can be quantitatively modeled out" (572).

[18] The Durbin-Watson statistic tests for the presence of first order autocorrelation between the residual and the lag 1 residual. The statistic value *(d)* lies between 0 and 4 with $d = 2$ representing no autocorrelation. Values close to 0 and 4 indicate positive and negative serial correlation, respectively (Schubert 1999).

[19] J. M. Gottman, *Time-Series Analysis: A Comprehensive Introduction for Social Scientists.* (Cambridge: Cambridge University Press, 1981) cited in (Schubert 2004)

Table 3-5. Time series first-order autoregression models summary for excerpts 1, 4, 7, and 12

Excerpt	Model	Model Fit Summary			Regression Coefficients		
		AR1	**Adj. R^2**	***d***	**MF**	**β**	**t**
E01	Musicians	.95	.16	.38	Loud_2	.68	6.0**
					Loud_4	.53	6.0**
					Loud	.40	4.6**
	Nonmusicians						
E04	Musicians	.97	.09	.43	Loud_2	.23	2.3*
	Nonmusicians	.96	.16	.39	Loud	.47	6.5**
					Loud_2	.34	4.2**
					Loud_4	.14	2.0*
E07	Musicians	.94	.01	.27	Temp_2	.12	2.1*
					Loud_4	.12	2.0*
	Nonmusicians	.96	.08	.26	Temp_2	.27	4.7**
					Loud_2	.21	3.5*
E10	Musicians	.93	.14	.40	Cent_1	.39	5.0**
	Nonmusicians	.92	.17	.74	Loud_2	-3.7	-4.6**
					Cent_1	.22	2.3*
					Temp_4	.18	2.2*

Legend: AR1 = coefficient for first order autoregressive term. Adj. R^2 = approximate model fit. *d* =Durbin-Watson statistic. MF = musical feature variable. β = standardized coefficient. t = t statistic. Loud = loudness. Temp = tempo. Cent = spectral centroid. Number of seconds of lag indicated after each musical feature variable. Significance levels: ** $p < .001$, * $p < .05$

Similar to Schubert's findings, tempo and loudness were the main musical features that were entered into the models. Loudness appeared in almost every model; in fact, loudness at various lags was the only musical feature included in the models for the gradual gesture types (E01 and E04). Tempo was included in the models for the sudden types (E07 and E10). For the features related to timbre, the texture predictor was not entered into any of the models and spectral centroid was only included in the models for E10.

For the gradual gesture types (E01 and E04), we speculate that the timbral parameters (instrumental texture and spectral centroid) and loudness were collinear, given that the level and spectral extent, both of which contribute to loudness, are directly affected by the number and variety of instruments. In regression models, collinearity is an issue when predictor variables are highly correlated. It can be diagnosed by calculating the tolerance, which is a reflection of the value of fit (1-R^2) (Schubert 1999, 312). All of the models' tolerance estimates were high (greater than 0.5), which indicates that there were no issues with excessive collinearity. Additionally, Pearson cross-correlation coefficients were lower than 0.7, revealing that there were no strong relationships among the variables. However, there were some weak to moderate relationships between loudness and texture/spectral centroid for the models of E01 and E04, as shown in Table 3-6 that reports the correlation coefficients for the relationships between the loudness predictors entered into the regression models and texture and spectral centroid at various lags. Due to the stepwise regression method, the inclusion of spectral centroid and texture in the model likely did not increase the predictive power, and as a result only the loudness parameter was retained.

Table 3-6. Pearson coefficients for cross-correlations with significant p-values between musical feature variables of loudness and timbral parameters (spectral centroid and texture) for the gradual gestural types

Excerpt	Model	MF	Cent	Cent_1	Cent_2	Cent_3	Cent_4	Text	Text_1	Text_2	Text_3	Text_4
E01	Mus	Loud	.36**	.50**	.22**							
		Loud_2	-.31**		.48**	.52**	.14*					
		Loud_4										
E04	Mus	Loud_2		.42**	.53**	.46**	.23**		.18*	.26*	.21*	
	Non	Loud	.53**	.46**	.23**			.26**	.21*			
		Loud_2		.42**	.53**	.46**	.23**		.18*	.26*	.21*	
		Loud_4				.42**	.53**				.18*	.26*

Legend: Mus = musician model. Non = nonmusicians model. MF = musical feature variables. Loud = loudness. Cent = spectral centroid. Text = Texture. Number of seconds of lag indicated after each musical feature variable. Significance levels: *****p* **< .001, ****p*** **< .05**

Visualizations

Emotional intensity

We graphed the average emotional intensity ratings for the musicians and nonmusicians to examine the evolution of emotional responses over time (see Figures 3-5 and 3-6).[20] The shaded clouds around the musicians' and nonmusicians' curves represent ±1 standard deviation. Given the variability, we cannot assume response coordination or that there are any statistically significant differences between the listener groups. However, we can observe general trends and note where the tendencies among the listener groups are similar or where they diverge.

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[20] We developed these graphs using the shadedErrorBar function from MATLAB (Campbell 2010).

The emotional intensity ratings of the gradual addition type (Figure 3-5) generally follow the gestural shape of the orchestration changes with an increasing trajectory towards the end of the excerpt. The ratings of the gradual reduction gestures, in contrast, reach a plateau and do not completely plummet at the end of the excerpt. Similar to the gradual addition type, the sudden addition gestures' (Figure 3-6) emotional intensity ratings increase towards the end of the excerpt, but feature a steeper slope surrounding the moment of textural change (shown by the vertical dotted line). It is important to note that E09 was initially categorized as a sudden addition due to the manner in which Debussy holds back several instruments until the climactic moment. Based on music-theoretical analyses in the companion paper, the gesture was subsequently reinterpreted as a gradual addition due to the overall expressive trajectory of orchestral growth.[21] The emotional intensity ratings of E09 also more closely resemble those for the gradual addition gestures with overall increasing intensification (no sharp increase at any particular moment). The sudden reduction gestures share a similar feature with those of the gradual reduction type in that they both present a plateau of high emotional intensity ratings even after the reduction of forces. These ratings will be discussed further below.

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[21] (Goodchild 2016a) [Chapter 2]

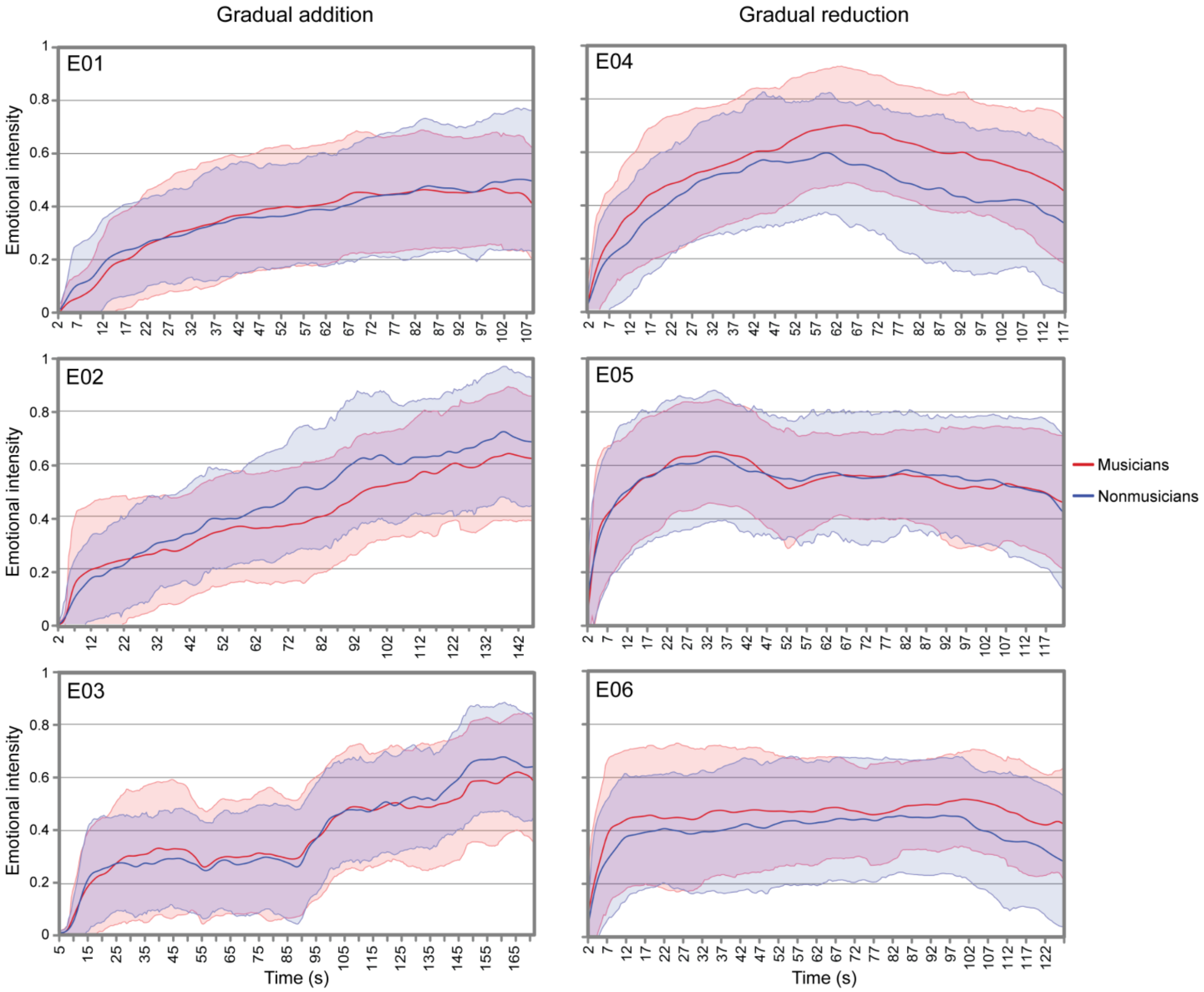

Figure 3-5. Average emotional intensity ratings for musicians (red line) and nonmusicians (blue line) for gradual addition and gradual reduction excerpts. Pink and light blue shaded regions indicate ±1 standard deviation from the average of musicians and nonmusicians, respectively. Overlapping areas are represented by purple shading.

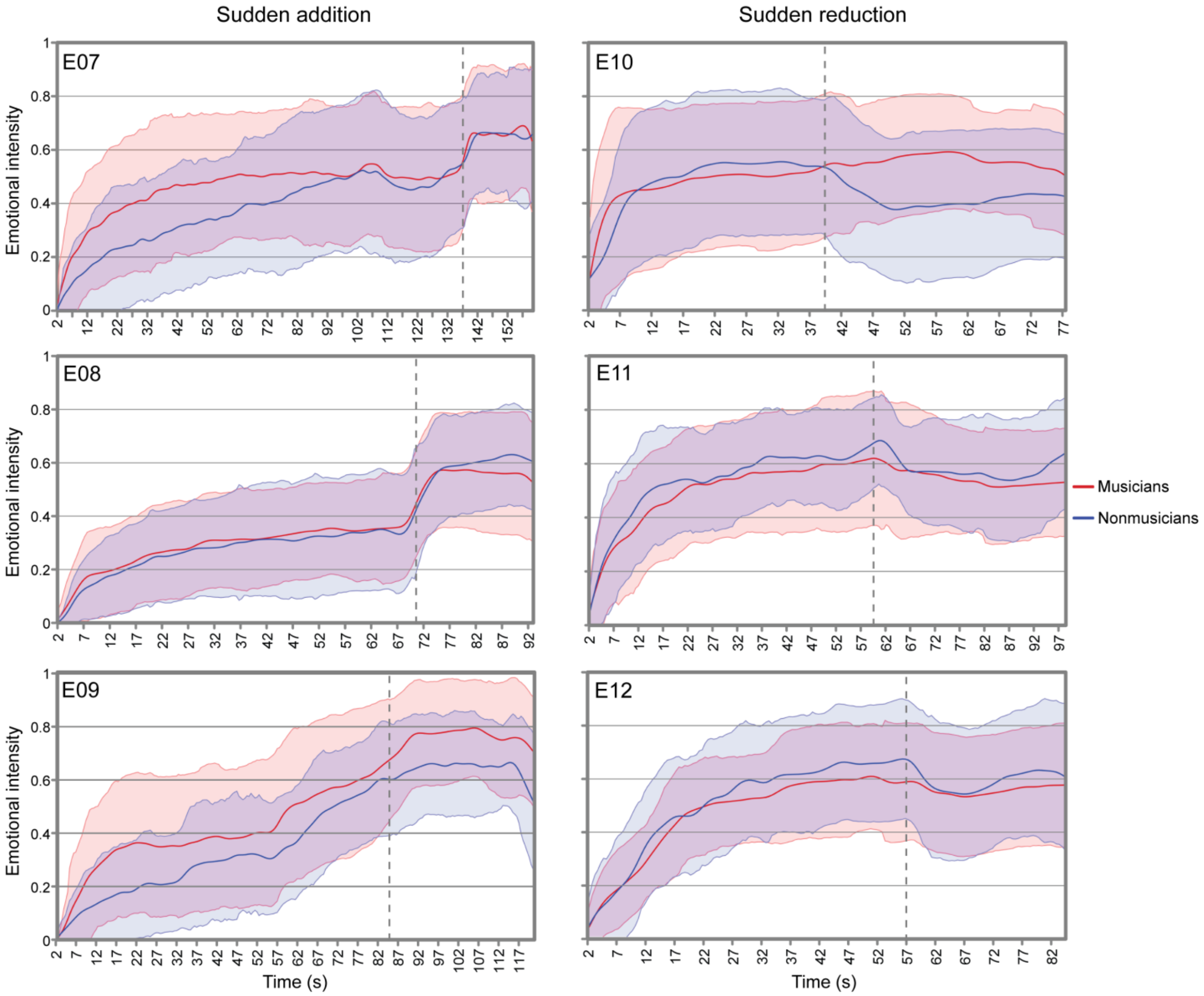

Figure 3-6. Average emotional intensity ratings for musicians (red line) and nonmusicians (blue line) for sudden addition and sudden reduction excerpts. Pink and light blue shaded regions indicate ±1 standard deviation from the average of musicians and nonmusicians, respectively. Overlapping areas are represented by purple shading. Vertical dotted line represents the moment of sudden textual change.

Emotional intensity and musical parameters

A visualization tool was developed in order to facilitate the analysis of the emotional response profiles in response to instrumentation changes and their interactions with other musical parameters. The visualizations for all 12 excerpts can be found in the Appendices A1-A12, as indicated in Table 3-1.This exploratory method creates a synoptic view of the excerpt by graphing together for visual comparison the emotional intensity slider ratings and the musical feature variables.[22] Time in seconds and the measure numbers are indicated on the x-axis. The texture parameter is displayed as a stacked bar graph with the instrument family indicated by colour. With this approach, one can view the textural density of each family and how it evolves over time. The musicians' and nonmusicians' mean ratings are superimposed and the remaining musical feature variables are stacked above for ease of reference. The scales of the y-axes were chosen for maximum clarity and comparison across excerpts. The y-axes for onset density and texture are adjusted based on the excerpt due to the wide range of the number of instruments used. Spectral centroid ranges between 0 and 1000 or 1500 Hz. Tempo spans 0 and 100 or 200 bpm. Loudness is constant between 0 and 100 sones. The contour parameter is constant between C_1 and C_8. The emotional intensity ratings are based on those reported in Figures 3-5 and 3-6; however, they have been normalized between 0 and 1 to show the maximum reached for the excerpt. This was chosen to focus on the changes in ratings rather than the absolute values. The companion paper provides a detailed music-theoretical analysis for each of the 12 excerpts.[23] The following section draws on these analyses, but focuses on the connection between the musical features and the resulting emotional responses in several examples of each type of orchestral gesture.

Gradual addition

Excerpts 1-3 (Appendices A1-A3) build large-scale orchestral crencendi, although each example constructs the constituent processes in different ways. In excerpt 1 (Mahler Symphony 1, mm. 1-32), Mahler systematically adds part after part in canon, resulting in a gradual intensification in the instrumental thickness, onset density, loudness, and spectral centroid. The emotional intensity ratings of the musicians and nonmusicians begin with a steep incline that arches towards the end of

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[22] All graphs were created in Excel (Microsoft, 2013) and Illustrator (Adobe Systems, 2007).

[23] (Goodchild 2016a) [Chapter 2].

the excerpt. Although the number of instruments remains small at the onset, the deliberate, slow-building orchestral swell, likely contributes to the increasing intensification of emotional intensity.

In excerpt 2 (Mahler, Symphony 2, I, mm. 254-302), the overall shape of increasing textural density is comparable to excerpt 1; however, the instrumental fabric accumulates through a process in which instruments drop out and reenter later in larger numbers. The musical features climax toward the end of the excerpt, with an expressive moment of *tempo rubato*, a spike in onset density, and the extended use of percussion. Similar to excerpt 1, few differences exist between the emotional intensity responses of the musicians and nonmusicians, with the ratings of both groups steadily increasing towards the end of the excerpt.

In excerpt 3 (Sibelius's Symphony 1, I, mm. 1-96), the gradual addition builds over several phases. The initial phase (mm. 1-28) features the clarinet and timpani, increasing anticipation for the response from the orchestra. The following phases result in waves of increasing and decreasing orchestral texture and onset density. The various instrumental combinations result in peaks and dips in spectral centroid and expand the overall *ambitus*. Unlike excerpts 1 and 2, the emotional intensity responses do not climb steadily toward the end of the excerpt. Generally following the shapes of the texture, onset density, and loudness parameters, the ratings plateau during the clarinet solo and then increase rapidly with the entry of the strings and faster tempo, ultimately peaking at the end of the excerpt.

Gradual reduction

The gradual reduction gestures (Appendices A4-A6) feature the decrease of the instrumentation and other musical features in a process of abatement.[24] Example 4 (Mussorgsky/Ravel, *Pictures at an Exhibition*, "Bydlo," mm. 39-64) exemplifies the process of

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[24] (Goodchild 2016a) [Chapter 2].

progressive lessening with the coordination of musical processes: the instrumental parts gradually fade out, reducing the onset density, loudness, and spectral centroid, while the ambitus narrows to only the double bass. Despite the evident concluding function, the responses exhibit persistent high emotional intensity ratings even at the end of the excerpt.

The other two examples expand the final process of the gradual reduction, adding a sense of prolonged stasis within the larger trajectory of the gesture.[25] In both excerpts, the initial process of reduction is brief, followed by a longer section with a low dynamic level, slow tempo, wide ambitus, and minimal onset density. In response, the emotional intensity ratings in excerpt 5 reach an early peak in measure 92 and reduce until measure 97, at which point they plateau toward the end of the excerpt. In excerpt 6, the emotional intensity ratings continue to climb and only begin to decrease at the end.

Overall, the gradual reduction gesture is not always scored as the reverse process of the gradual addition. Additionally, the emotional intensity ratings do not mirror the reduction of musical features, instead resulting in a sustained lingering effect of high emotional intensity.

Sudden addition

The sudden addition category examples (Appendices A7-A8) use an anticipatory signal (shown with a bracket) before the sudden textural change, which likely prepares the listener for the upcoming wall of sound. In these examples, the signal involves ascending arpeggios with instruments entering in successively higher registers, causing a sudden increase in spectral centroid, loudness, tempo, and onset density, as well as a rapid expansion of the upper range of the ambitus.[26] The excerpts also feature the use of silence to emphasize the sudden change in instrumental forces: excerpt 7 has rests after the anticipatory signal, whereas excerpt 8 uses silence beforehand. In both

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[25] (Goodchild 2016a) [Chapter 2].

[26] (Goodchild 2016a) [Chapter 2].

cases, the musicians respond to anticipatory signal by sharply increasing their slider ratings to reach their peak in advance of the sudden addition. For the nonmusicians, however, a similar spike occurs after the blast, a delay of several seconds. The peak emotional intensity values do not occur until toward the end of the excerpt and not directly at the sudden addition. This may be related to the way the musical features continue to vary expressively (excerpt 7) or sustain the intensity (excerpt 8) after textural change.

Sudden reduction

In the sudden reduction gestures (Appendices A10-A12), the moment of textural change marks a structural rupture in the dramatic trajectory of the excerpt.[27] The main feature is the abrupt reduction from full forces to a subgroup of the orchestra and the sudden drop in loudness. In all examples, the *ambitus* remains wide, which emphasizes the thinned texture, and the spectral centroid varies based on the differing instrumental combinations. In excerpts 11 and 12, the tempo stays constant, driving the action forward after the drop-off. In excerpt 10, the tempo plummets before the textural change and continues to be held back, creating the effect of time being suspended.

In all three excerpts, the musicians' and nonmusicians' ratings demonstrate a sustained lingering effect of high emotional intensity that goes against the large reduction in musical forces. The high emotional intensity may be linked to the combination of the surprising textural change followed by the tense atmosphere in the reduced texture.

Excerpt 10 also features an intriguing difference between the ratings of the musicians and nonmusicians. The musicians' ratings generally increase in intensity throughout; however, the nonmusicians' ratings peak before the drop-off and trail behind the changes in loudness and tempo. Even the nonmusicians' ratings reach a plateau and do not completely plummet.

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[27] (Goodchild 2016a) [Chapter 2].

DISCUSSION

Retrospective ratings

The retrospective ratings indicated that participants' moods did not change significantly from the beginning to the end of the experiment. They reported that the slider was easy to use and was not intrusive on the listening experience. Additionally, the ratings of familiarity were low for both the musicians and nonmusicians in general. Musicians were significantly more familiar than nonmusicians for four excerpts; however, visual inspection of the visualizations for excerpts 4, 5, 9, and 12 did not reveal any notable differences in responses to them.

As predicted, the number of chills for the sudden addition gestures was significantly higher compared to the other gestural types. This finding confirms the results of several other studies that associated chills with sudden or unexpected changes in texture and loudness (Guhn, Hamm, and Zentner 2007; Sloboda 1991; Grewe, Nagel, Kopiez, and Altenmuller 2007).

Median emotional intensity ratings

Based on the numerous findings in the literature that associated additive orchestration techniques (e.g., orchestral crescendi and sudden orchestral tutti) with emotions of high intensity, we predicted that the emotional intensity ratings would be higher for the additive gestures compared to the reductive gestures. However, the ANOVA results revealed that the opposite was true: the median emotional intensity ratings were higher for reductive gestures compared to additive ones. We also predicted that the variability, as measured by the interquartile range, would be higher in sudden excerpts, in which a dramatic change in orchestral texture would likely cause a distinct spike in emotional intensity. The results of the ANOVA revealed that direction, not time course, showed a distinction: the additive gestures had higher response variability compared to the reductive gestures.

Examination of the visualizations provides insight into these findings. For both gradual and sudden reductions, the emotional intensity ratings had an initial increase at the beginning of the excerpt followed by relatively little decrease in intensity over the remainder of the excerpt. This plateau of elevated emotional intensity resulted in higher median ratings and low variability. In contrast, the ratings generally climb over the course of the excerpt to the climax for the gradual and sudden addition gestures, causing lower median ratings and higher variability. This analysis also highlights the importance of considering the evolution of emotional intensity ratings in context. Measures of central tendency, like the grand mean or median, are not able to capture the full picture, particularly when studying responses to musical excerpts with dynamic and dramatic processes.

Time series regression study

Examination of the time series regression results reveals distinct differences in the parameters contributing to emotional responses for the four orchestral gesture types. Loudness was the only variable entered into the models for the gradual gestures. For the sudden gestures, tempo was included in addition to loudness. Spectral centroid was only included for the sudden reduction gesture.

Several factors call into question the results of the regression study. Despite the first order difference transformation and autoregressive adjustment, the effects of serial correlation were not completely removed in all of the models. The emotional intensity ratings were largely influenced by the preceding context and not the contributions of the musical features. As a result, the validity of the regression models was compromised.

Through inspection of the visualizations, it becomes evident why the regression analyses could not account for most of the variance in the data. There is not a direct one-to-one correspondence between the emotional intensity ratings and the musical feature variables employed.

In his regression study, Schubert selected four pieces that generally capture a specific mood represented within the four quadrants of the two-dimensional emotion space of valence and arousal. In contrast, we chose pieces that feature and are characterized by large-scale expressive changes. Therefore, a linear combination of the parameters cannot account for the majority of the variance of the emotional response ratings. The direction and magnitude of the effect of each variable varies throughout the excerpt and interacts with the musical context created by other parameters that have not been included as predictors (e.g., harmonic tension).

The exclusion of the timbral predictors (texture and spectral centroid) from most of the models is especially problematic for our study on changes in orchestration. Although texture and spectral centroid were not found to be excessively collinear with loudness, there were low to moderate relationships between these variables. The addition of spectral centroid and texture in the model likely did not increase the predictive power above that of loudness in the stepwise regression method. Therefore, the analysis does not necessarily indicate that timbral musical features do not play a role in the emotional responses to orchestral gestures; however, the regression approach used does not allow for the contributions of the textural parameters to be separated from that of loudness.

The low goodness-of-fit values for the sudden gestures are likely related to the variability and abrupt changes of the responses and musical features. Creating separate regression models for the periods before and after the sudden change may be beneficial in this regard. We suspect that it may be useful to consider various transforms of the variables in future work to overcome issues with the non-linearity of the relations between the musical features and the behavioural data. Along the lines of the approach of Dubnov, McAdams, and Reynolds (2006), windowed multiple regression that allows the relative weights of the different predictors to vary over time may be beneficial.

Visualizations

Each of the orchestral gesture types feature distinct emotional response profiles. For the gradual addition type, participants' ratings steadily climbed towards the end of the excerpt along with increases in musical features, particularly instrumental texture and loudness. For the sudden addition type, the emotional intensity ratings increase sharply at the sudden textural change, but peak towards the end of the excerpt, which indicates that the interaction of musical features after the textural change contribute to the climax of the gesture.

The gradual reduction excerpts feature a reduction in spectral centroid, loudness, texture, onset density, and range between the upper and lower voices. The emotional effect of the gradual reduction, however, is not the reverse of the gradual addition. The emotional intensity ratings plateau and remain high even at the end of the excerpt. Similarly, the emotional intensity responses to the sudden reduction excerpts are not the opposite of those in response to the sudden addition type. The moment of sudden textural reduction comprises a structural rupture in the dramatic trajectory, resulting in persistent high emotional intensity despite decreases in loudness, onset density, and musical texture. This lingering effect relates to findings by Gabrielsson (2010), who reported that the effects of strong experiences to music are long-lasting. It could be argued that the prolonged high emotional intensity ratings may be an artifact of the experimental design in that participants did not know when the excerpt would end; however, we argue that this anomaly is likely related to an "afterglow" effect, in which emotional arousal continues after dramatic events and even after the music has stopped (Schubert 1999; Schubert 2012).

The visualizations reveal slight differences between the ratings of the musicians and nonmusicians in relation to the sudden gestures. Due to their greater exposure to orchestral music, the musicians may recognize anticipatory signals and, as a result, their emotional responses were heightened before the onset of the dramatic moment of sudden addition. The musicians may also be more sensitive to factors that are not yet coded, such as harmonic tension. This finding is in line with previous studies, such as Steinbeis, Koelsch, and Sloboda (2006), who investigated the effect of harmonic expectancy violations on brain processing of emotional stimuli. Responses did not differ in amplitude between musicians and nonmusicians, but responses were earlier, suggesting that musicians had enhanced processing abilities of harmonic expectancy violations and greater sensitivity to stylistic violations.

The nonmusicians appear to be more directly affected by loudness and tempo changes and trail behind variations in these features, as seen in the delay in the responses compared to musicians in E07, E08, and E10. Similarly, Farbood's (2012) musical tension study found that musicians were more sensitive than nonmusicians to changes in certain musical features (e.g., harmony). The dissonant harmony after the sudden reduction, as analyzed in the companion paper,[28] may explain the striking difference in emotional intensity ratings between the musicians and nonmusicians in E10.

We propose that the visualization provides a crucial tool for analysis by moving beyond anecdotal or descriptive accounts of musical processes. The exploratory approach provides a synoptic view of the excerpt, allowing for the investigation of score-based information (instrumental texture, onset density, and contour), performance-based features (loudness, spectral centroid, and tempo), and experimental data (emotional intensity ratings). In future work, we plan on including other musical-feature overlays, such as phrase structure and harmonic tension, in order to better understand the interaction between orchestral texture and other musical parameters.

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[28] (Goodchild 2016a) [Chapter 2].

Limitations of the study and future work

A limitation of the present study is the use of a single recording of each excerpt as a representative performance. In future work, multiple recordings could be consulted in order to examine the role that performance features play on the emotional force of the gestures. Expressive factors, such as performance timing and dynamic changes, contribute to emotional responses and can highlight certain compositional choices, such as the anticipatory signal before a sudden addition or the surprise of the moment of the sudden reduction. Using the visualizations for comparison of particular recordings and the resulting emotional responses would be useful in this regard.

Presently, the score-based musical features were manually coded and the visualizations were created individually—a labour-intensive approach that increases the possibility of errors. In future, it would be beneficial to extract features automatically from symbolic scores. Additionally, an automatic process for assembling the individual graphical representations would accelerate the process and reduce the chance of error.

Another limitation of the regression study and analyses of the visualizations is related to the use of mean ratings of emotional intensity. As discussed above, this approach is problematic due to the response variability across participants. Activity analysis, currently being developed by Upham and McAdams (2014), is an analytical approach that focuses on particular active types of events in continuous responses (e.g., increases in arousal ratings above a certain threshold), considers the coincidence of a given activity over multiple responses to the same stimulus, and statistically evaluates response coordination. The researcher defines the type of response event, determines whether the timing of the event is consistent across participants, and then investigates which aspects of the stimulus elicit this response. In future, we plan on employing activity analysis to assess response coordination within and across the musician and nonmusicians groups, as well as to pinpoint statistically significant moments of local activity for increasing or decreasing emotional intensity. This type of analysis would assist in disentangling instances where participants' responses are coordinated and where they diverge and how these instances relate to important moments within the shaping of orchestral gestures.

Overall, this exploratory study explored listeners' responses to orchestral gestures in order to gain a better understanding of the evolution of emotional intensity in connection to orchestration changes and other musical features. This study offers important contributions to the research on music and emotion. The four types of orchestral gestures provide a framework to interpret the previous empirical findings related to gradual and sudden textural changes. The visualization tool offers a qualitative and quantitative method to study score-based features, performance-based features, and emotional responses within a large-scale context. Additionally, the study demonstrates the need for more sophisticated time series approaches to account for dynamic changes of musical parameters and emotional intensity ratings. We suggest that the results of the study provide a foundation towards a theory of orchestral gestures grounded in perceptual testing.

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(ICMPC12) in Thessaloniki, Greece in July 2012 and at the 21st International Congress on Acoustics (ICA 2013) in Montreal, Canada in June 2013. An earlier version of the theoretical analysis was presented and reported in the abstract book at the joint meeting of the American Musicological Society, Society for Ethnomusicology, and Society for Music Theory (SMT) in New Orleans, USA in November 2012.

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CHAPTER 4

RECOMPOSITION AND REORCHESTRATION

In addition to the lack of music theoretical investigations related to timbre and orchestration, there are few analytical tools or methods developed to assist in its study. Chapter 4 develops on the prevailing informal use of recomposition to advance a hypothesis-testing method, which can also be used to investigate the role of orchestration. In the first section, the method is demonstrated through a case study that tests specific features of the sudden reduction gesture left unresolved from Chapters 2 and 3. The second section utilizes the method to examine a phenomenon related to the connection between orchestral brightness and emotional valence.

This chapter is based on the following research article:

Goodchild, M. "Recomposition and Reorchestration." Manuscript prepared for submission.

ABSTRACT

Recomposition is used informally as an analytical tool by music theorists. In the first section of this paper, I propose a method of recomposition using hypothesis-testing as a mechanism for investigating and theorizing about musical phenomena. The method involves articulating an initial hypothesis, selecting a representative musical example, recomposing or reorchestrating the passage to test the hypothesis, comparative listening to the original and new version, and evaluating the results of this process. I demonstrate the application of this method with a case study of an excerpt from Bruckner's Symphony 8, I. In the second section, the method of recomposition is used on a larger scale to investigate the effects of independently modifying instrumentation to adjust relative brightness. The hypothesis-testing method for reorchestration provides a unique opportunity to study various approaches to brightening and darkening in particular types of passages. Expert reorchestrations of three excerpts were created to produce bright and dark versions. I analyze the scores, conduct comparative listening, and evaluate the various strategies of the reorchestrations. The discussion includes the responses from post-project interviews and an analysis of the effects of the adjustments in relation to the specific musical contexts.

INTRODUCTION

Music theorists use the analytical tool of recomposition—the selective modification of musical details—in order to examine alternative possibilities of musical structure (such as phrasing, metrical patterns, and motivic ideas) and to highlight certain features of the piece. As a personal anecdote, I often use the technique in teaching, for example, recomposing at the piano to demonstrate the effect of changing the type of cadence at a particular structural moment. In music-theoretical research, I have also created recompositions to support an analytical argument, such as reordering the events in a Brahms *Intermezzo* to represent a more normative arrangement, thereby revealing the subtlety of the grouping structure and gestural ambiguity of the original. Indeed, it is not difficult to find examples of recompositions in recent music-theoretical discourse. However, theorists rarely address the act of recomposition itself. What is involved in the process of recomposition? What can the process of recomposing reveal about the music? Why have so many analysts found it to be extremely effective in demonstrating their analytical point of view?

Both Nicholas Cook and Leonard B. Meyer have argued that composition and analysis are intricately related. In his *Guide to Musical Analysis,* Cook (1987) explains the natural link between composition and analysis: "To analyze a piece of music is to weigh alternatives, to judge how it would have been if the composer had done this instead of that – it is, in a sense, to recompose the music in a way that normal concert-hall listening is not" (232). Similarly, Meyer (1989) writes, "To appreciate fully what something is—to comprehend its significance—is to have some notion (however informal or unformulated) about what it might have been. […] the road actually taken is invariably understood partly in terms of those not taken" (32). He returns to this topic later and muses, "Why, out of all the possible alternatives that the composer might have devised or considered for in some work, was this particular one chosen rather than some other?" (Meyer 1989, 135). For Cook and Meyer, the aim of analysis, through a compositional lens, is a deeper appreciation and understanding of the work.

Cook (1996) provides an even more overt connection between analysis and composition in his pedagogical text *Analysis through Composition.* His aim is for students to learn basic theoretical concepts through various musical activities, including writing arrangements, composing variations, expanding passages, and comparing composers' sketches with complete works. Several activities engage students in the process of recomposition; one exercise in particular involves adapting existing phrases to end in different keys and then examining the results of these changes. By undertaking this process, students would likely develop a better understanding of the large-scale structure and tonality.

More recently, Melissa Hoag (2013) explicitly advocates the use of recomposition to foster music appreciation in the theory classroom. Drawing on Meyer's notion of experiencing "what might have been," Hoag provides examples of various recompositions of melodies, harmonic progressions, and phrase structures. By discussing the musical features that differentiate the versions, the aim is to refine and heighten students' abilities in order for them to gain a deeper appreciation for the music. Hoag (2013) argues that "hearing the alternate possibilities awakens their ears to the small differences among works that create such diverse musical realizations" (57).

In academic music-theoretical discourse, recompositions are commonly created to represent a more normative version to which the original version is compared.[1] This comparison is meant to reveal the subtleties of the original that make it expressive or unique, often in relation to phrase structure or harmonic processes. As a recent example of this method, Harald Krebs' (2010; 2014) hypothetical settings of poems follow a basic rhythm of declamation in order to highlight

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[1] Another interesting historical case of recomposition involves critics' revisions of Mozart's String Quartet K. 465 to rectify the ostensibly offensive dissonances. For further historical and analytical discussion, see Vertees (1974) and DeFotis (1982).

Schumann's expressive declamation in his late Lieder. Krebs (2014) defines his own approach as "analytical and in part compositional," (§1.3) intended to uncover nuances in Schumann's setting. Although Krebs uses the word recomposition in the title and abstract, he does not explicitly define the technique or refer to prior uses in the literature. Therefore, Krebs employs recomposition as an established method to demonstrate his analytical argument. Indeed, many theorists, such as William E. Caplin and William Rothstein, have also used this technique without requiring any further explanation.[2]

Recently, Matt L. BaileyShea (2007) criticizes the limited application of recomposition currently employed by music theorists. He views the recompositions that are typically offered by theorists as a foil, constructed to be lesser than the original composition in support of an analytical objective. He offers another type of recompositional strategy called "creative recomposition," in which he splices together various Goethe settings by Schubert, Schumann, and Wolf to create a new, unified composition. By juxtaposing snippets of the various settings, his aim is to hear the original works in new ways, as well as highlight and construct intertextural associations. BaileyShea (2007) explains, "The analysis informs the music; the music is an analysis" (§7). His approach has great potential as a creative process that brings together the fields of theory, composition, and performance, thereby promoting new ways of thinking about recomposition.

David Temperley (2001) has taken a more empirical route in his use of recomposition. In order to investigate how the details of a piece affect expressive representations, Temperley (2001) conducts an "experiment in recomposition," which he defines as "selectively altering certain details of a piece, to see what kind of changes result in structure and effect" (349). He creates ten recompositions of a short section from Beethoven's Sonata Op. 10 No. 3, altering a single detail in each case to investigate the resulting effect. For each recomposition, Temperley defines the

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[2] See for example, Caplin (1998, 40) and Rothstein (1989, 23–24).

adjustment(s) and then discusses the effects related to harmonic tension, motivic connections, rhythmic profile, and meter. Some of the changes produce more or less obvious effects, which he describes as "radical," "subtle," or "negligible." Although he does not specifically ask the reader to play through his recompositions, it appears that Temperley expects that the reader will be able to "hear" the effects of the changes in some manner.

RECOMPOSITION METHOD

As discussed above, there is a long-standing precedent in the music-theoretical community in the use of recomposition as an analytical strategy. Its application in a systematic manner, however, could provide a mechanism for testing hypotheses about musical phenomena as part of the development of music theories. Inspired by Temperley's (2001) "experiment in recomposition," I propose a hypothesis-testing method of recomposition that comprises several steps, shown in Figure 4-1.

The first step involves articulating an initial hypothesis about a musical feature of interest. The hypothesis could be explicit or more exploratory in nature. In the second step, the researcher would select a representative musical passage that exemplifies the feature in question, analyze the passage, and then begin the recomposition process. This process could entail making an adjustment to test the hypothesis, or several recompositions could be created by subjecting the passage to a series of adjustments. The third step, which has only been implicit in the past, is to listen to the effect that the adjustments have made through a detailed comparison of the original and recomposed versions. In the fourth stage, the researcher evaluates and analyzes the results of the comparative listening, attempting to distill an understanding of the essential aspects of the musical feature. The aim is for the researcher to come to an analytical conclusion and ultimately to contribute to a theoretical understanding of the musical phenomenon in question. The process is not strictly linear. At the evaluation stage, the researcher may need to refine the recompositions, which will lead back through the stages of recomposition, comparative listening and evaluation. Or, the researcher may need to refine the initial hypothesis, prompting the return to the beginning of the process.

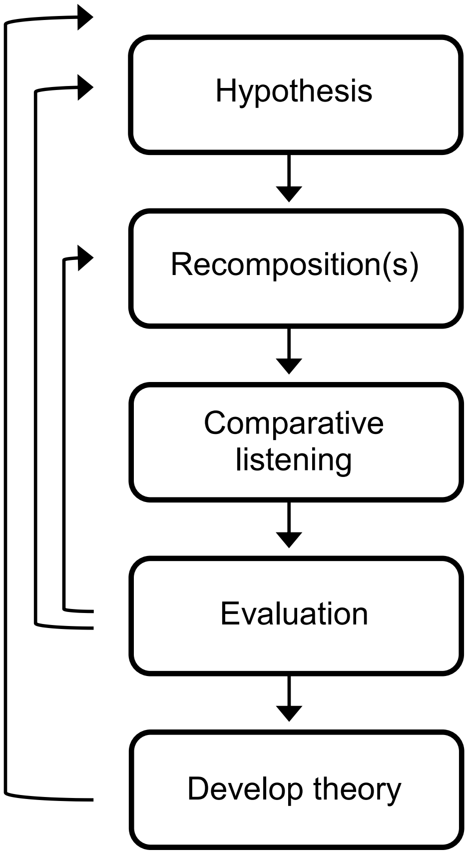

Figure 4-1. Diagram of hypothesis testing using recomposition

Reorchestration—a musical activity related to recomposition—has been used by composers in various capacities for centuries. Reorchestration could be considered as a type of recomposition that involves making adjustments related to instrumentation. Like recompositions, reorchestrations are used extensively in pedagogical settings. Composition students learn how to score for different ensembles, especially translating from piano to orchestra and vice versa. Historically, composers have also revised their own works or other composers' works to update the orchestration, often due to technical improvements of instruments or to correct/improve ostensibly flawed instrumentation. Some famous examples include Mahler's revisions of Schumann's orchestration (Franke 2006), Mahler's versions of Beethoven's 9th Symphony (McCaldin 1980), Rimsky-Korsakov's arrangements of Mussorgsky's operas (Boyd, n.d.), and extensive revisions to Rameau's instrumentation (Sadler 1981).

I propose that music theorists and researchers could investigate the role of orchestration using the hypothesis-testing method of recomposition. Using the method described above, researchers could develop a hypothesis, compose reorchestrations to test the hypothesis, conduct comparative listening, and evaluate the results. I believe this method would be an accessible entry point for examining orchestration, a topic that is missing in current music-theoretical research. For the purposes of the following discussion, the distinction between the acts of recomposition and reorchestration relate to the nature of the adjustments: reorchestrations adapt the instrumentation, whereas recompositions modify other musical parameters, such as phrase structure and pitch content. One potential limitation in the reorchestration process is the comparative listening stage. How could the researcher actually hear the reorchestrated versions without hiring an orchestra? New software currently being developed circumvents this issue through realistic renderings of full orchestral scores (discussed further below).

In this paper, I will demonstrate the utility of recomposition (and reorchestration) as an analytical tool. In the first section, I discuss a case study in which the hypothesis-testing method of recomposition and reorchestration is employed to gain a better understanding of sudden reduction orchestral gestures. In the second section, I outline a hypothesis regarding orchestral brightness, analyze three expert reorchestrations, and discuss the various techniques used to achieve the effects.

CASE STUDY

Background

Goodchild outlined a typology of orchestral gestures—large-scale, goal-directed, coordinated instrumentation changes that occupy one formal function—comprised of four types based on time course (gradual or sudden changes in instrumentation) and direction (addition or reduction of instruments).[3] The study analyzed three sudden reduction excerpts: Bruckner's Symphony 8, I (mm. 218-265), Dvořák's Symphony 9, I (mm. 200-286), and Holst's "Uranus: The Magician" from *The Planets* (mm. 193-236). The sudden reduction gestures in these examples coincide with major structural events. For the excerpts by Bruckner and Dvořák, the sudden reduction contributes to the tonal and thematic processes between the development and recapitulation sections of the sonata form. Similarly, the Holst excerpt features a sudden reduction that instigates the final section of the movement.

In all three cases, the gesture also enhances the structural subversion that is underway. In the Dvořák excerpt, the sudden reduction occurs at the breaking point of the development section (after several failed attempts to move to the goal dominant), redirecting towards the threshold of the recapitulation within the reduced instrumental texture. The sudden reduction of the Holst excerpt halts the relentless march theme after the arrival on a surprising climactic chord, followed by the rapid change from the orchestral *tutti* to the string section at *pianissimo* dynamic. The Bruckner excerpt (discussed further below) contributes to the tonal and thematic structural collapse bridging the development and recapitulation functions of the movement.

Based on analyses of these examples, the sudden reduction marks the turning point of an ongoing process that has abruptly and perhaps unexpectedly come to a halt. This inherent quality differentiates a sudden reduction from orchestral contrasts that demarcate musical groupings, such

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[3] (Goodchild 2016a) [Chapter 2]

as antiphonal exchanges or sectional divisions in which each alternating musical segment is scored with different instrumentation. It is not clear, however, how the structural features, such as the arrival point before the drop-off and the instability of the harmonic context, contribute to this climactic effect.

In an exploratory experiment investigating listeners' emotional responses in relation to changes in instrumentation found in orchestral gestures, a distinct lingering effect of high emotional intensity for gradual and sudden reductive orchestral gestures was found.[4] For the sudden reduction type, the diminution of orchestral forces is integral to the gesture, but it is uncertain how other aspects of the instrumentation contribute to the overall effect.

To address the above questions, I employ the step-by-step method of recomposition and reorchestration. The following section reports the results of a case-study in which the method is used to analyze the Bruckner excerpt in order to investigate features of the sudden reduction gesture.

Analysis of the Bruckner excerpt

As discussed above, the Bruckner excerpt comprises a sudden reduction gesture that contributes to the tonal and thematic structural collapse bridging the development and recapitulation (see score in Appendix B1). Analysts and critics have largely disagreed regarding the formal divisions of the movement.[5] The discrepancy resides in the manner in which Bruckner blurs the boundaries of the development and recapitulation. One of the issues involves the thematic reprise at measure 225. As Benjamin M. Korstvedt (2000) describes, "Gesturally this feels like a recapitulation, and it does restate the opening theme at its original pitch level, yet the original theme itself deflects the tonic key, and Bruckner capitalizes on its tonal ambivalence" (34). Similarly, Julian Horton (2004) notes

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[4] (Goodchild, Wild, and McAdams 2016) [Chapter 3]

[5] For further discussion of the analytic disagreement, see endnote 13 in Korstvedt (2000, 118).

that this thematic recapitulation is the goal of the development section, but the tonal instability creates a structural problem. The theme is stated three times, stepping up by a third each time, but coming to a halt at measure 249 on the cadential six-four harmony.

Both authors discuss this climactic moment in terms of the tonal and thematic breakdown. Korstvedt (2000) states that "the recapitulation of the opening material bridges the end of the development and the return of the second theme group in such a way that the crucial division of development and recapitulation—a juncture freighted with structural meaning— is artfully blurred" (28). Along the same lines, Horton (2004) asserts that the development and recapitulation overlap to their mutual detriment, resulting in a structural collapse. Horton does not comment on the orchestration or instrumental texture that underscores this climatic and structural collapse. Korstvedt (2000, 35) mentions very few details, such as the "oddly austere passage," and briefly lists the instruments engaged in the various thematic snippets, but not the moment of the sudden reduction itself.

In fact, several orchestral features contribute to the remarkable effect of the structural rupture. Leading up to the drop-off point, Bruckner creates a sense of imminent arrival, which has abruptly and unexpectedly come to a halt. The arrival point with full forces on the C-minor harmony is fleeting, since the six-four is left unresolved as it dissipates into the abyss. The moment of the sudden reduction leads to a striking section that features a stark, bare texture, which picks up on several threads from the preceding material (mm. 225-249). First, the descending chromatic four-note motive returns in diminution driving to the dominant scale degree in the cello and bass. Second, the melody featuring the Bruckner rhythm (duplet plus triplet), originally scored for the woodwinds (flutes, oboes and clarinets), recurs in the flute in a slightly altered form outlining the C-minor triad. Third, the dotted rhythmic pattern of the brass returns in the trumpets on a bare octave emphasizing the tonic. Finally, the repetition of the small thematic cells and the pull to the dominant and tonic poles creates an atmosphere of tension and instability.

Therefore, the orchestration of the sudden reduction gesture is integral to the effect of the structural collapse of the sonata form movement. Several questions remain unanswered about this excerpt and sudden reduction gesture. These questions will be explored through recompositions and reorchestrations, described further in the following sections.

Recompositions and reorchestrations

All of the recompositions can be found in Appendices B2-B6. Realistic acoustical renderings of the original and recomposition/reorchestration versions were created using the Digital Orchestra Simulator (DOSim), an orchestral rendering environment currently being developed by Bouliane and Baril (Bouliane and Baril 2014). The system allows for precise control of real instrument samples and various performance parameters, such as gradients in dynamics, attack speeds, vibrato rates and control, bowing speeds and timings, and balance within and across instrumental families. DOSim uses Finale (Make Music) for music notation, Kontakt 5 (Native Instruments) as a sampling engine, Logic Pro (Apple) for stereo mixing, and various recorded sound samples from the Vienna Symphonic Library (VSL GmbH, 2014). The performance interpretation was held constant across versions.[6] To stream these sound files, refer to the supplemental material.[7]

Recomposition: Deceptive vs. evaded

As described above, measure 249 marks the culmination of the tonal and thematic breakdown bridging the development and recapitulation sections. The instrumental forces drop off

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[6] Anton Bruckner, *Symphony no. 8,* with the Wiener Philharmoniker, conducted by Pierre Boulez, recorded 1996. Deutsche Grammophon, 2000.

[7] http://sites.music.mcgill.ca/orchestration/projects/dosim-reorchestration/

and the reduced atmosphere emerges from beneath the reverberation as a direct consequence of this structural subversion. In other instances of a sudden reduction in which instrumental forces rapidly diminish, the drop-off occurs at the moment of the expected arrival, such measure 63 in "Great Gate of Kiev" from *Pictures at an Exhibition* by Mussorgsky, orchestrated by Ravel. The former case is analogous to a deceptive cadence, in which the final tonic harmony of an implied perfect authentic cadence is replaced by another chord, often the submediant;[8] however, the substitute chord does not completely fulfill the expected sense of closure. The latter case is comparable to a cadential evasion, in which the final tonic harmony of an implied cadence fails to materialize. At the point where the resolution is expected, a new beginning is initiated. It is unclear whether there are functional differences between the deceptive and evaded types. By recomposing the deceptive sudden reduction of the Bruckner example to resemble an evaded type, we can investigate the features of each type in order to better understand their individual functions. Additionally, we can gain a better understanding of the compositional choices made by Bruckner for this particular sudden reduction gesture.

Appendix B2 contains measures 248-268 of the recomposition. To create an evaded effect, the chord on the downbeat at measure 249 is removed, leaving only the instruments that continue in the reduced atmosphere (flute, timpani, cello, and bass). As a result of this change, the chromatic eighth-note descent to the dominant scale degree in the bassoons, trombones, and tuba is cut off in measure 248. Similarly, the rhythmic motive of a dotted quarter and two sixteenth notes in the horns is abandoned.

As can be heard in comparing the DOSim renderings of the original and recomposition, the alteration changes the overall effect of the sudden reduction, creating greater sense of loss at the drop-off point. In the original version, the arrival point with full forces marks the moment of

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[8] See the discussion of cadential deformations in Caplin (1998).

structural collapse due to the following rapid dissipation of forces. In the recomposition, only the timpani plays the tonic scale degree. The denial of expectations further minimizes the arrival on the home key harmony to the point of near negation. The penultimate chord is left unresolved, with the subsequent tonal context slowly revealed through the flute arpeggio. The resulting section of reduced texture sounds disconnected from the previous material.

Evaluation of the original and recomposition reveals that the original sudden reduction version relies on the prevailing conflict of structural, tonal, and orchestral processes. On the one hand, the arrival on the home key tonality marks a pivotal arrival point. On the other hand, the six-four inversion and the abrupt reduction in orchestral forces mark the breakdown of the ongoing processes. This conflict—triumph turned to defeat—is an essential aspect of the sudden reduction gesture and the larger structural processes in the Bruckner example. The recomposition to an evaded type removes this conflict, leaving only the effect of a structural division, dividing the material before and after the drop-off. Therefore, the recomposition clarifies the crucial features of the original sudden reduction gesture. Although the deceptive and evaded types harness the concept of discontinuity, their functions and effects vary within the larger context and are not interchangeable.

Recomposition: Tonal instability

In the Bruckner, Dvořák, and Holst excerpts, the sudden reduction gives way to a harmonically ambiguous or dissonant section. In a previous listening experiment, one of the hypothesized causes of listeners' high emotional intensity ratings was related to the tense, unstable harmonic contexts after the drop-off points.[9] In the Dvořák excerpt, the climactic leading-tone diminished seventh chord leads to a sequence of unresolved dominant seventh chords. The Holst excerpt features a sustained dissonant subdominant ninth chord after the sudden reduction of

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[9] (Goodchild, Wild, and McAdams 2016) [Chapter 3].

forces. After the moment of sudden reduction in the Bruckner excerpt, the cadential six-four harmony is left unresolved, emphasizing the minor tonality and the pull to both the tonic and dominant poles. Recompositions of this Bruckner excerpt will test the role of the harmonic context in the section of reduced texture after the drop-off.

Appendix B3 contains measures 248-268 of the recomposition, in which the tonality is altered from C minor to C major. All of the lowered scale degrees (B-flat, E-flat and A-flat) are raised a half-step. The chromatic descent in the cello and bass from B-flat to G is converted to a diatonic descent from the tonic to the dominant.

Comparing the DOSim renderings of the original and recomposition, the loss of the chromatic descent eliminates the pull to the dominant and instead emphasizes the tonic scale degree, thereby destroying the tonal instability of the passage. As a result of this change, the arrival on the C major chord represents the goal of the passage and the following reduced texture appears to function as a series of codettas within a closing section, reinforcing the arrival of the tonic harmony. Therefore, the abrupt change to major tonality and the creation of tonal stability eliminates the effect of structural rupture. It is likely that listeners' emotional intensity ratings would plummet after the drop-off of the recomposition if tested experimentally. Based on these findings, the result of the recomposition is extremely unconvincing, perhaps even verging on humorous.

The results of this analysis do not preclude the possibility of a sudden reduction leading to a major tonal context. However, it does indicate that the sudden reduction of orchestral forces must work in combination with other harmonic and formal elements. In other words, the drop-off in instrumental texture is necessary but not sufficient to achieve the expressive effect of a sudden reduction gesture.

Reorchestrations: Orchestral families

The above recompositions altered structural and tonal aspects of the excerpt. How does the choice of instrumentation affect the sudden reduction gesture? In the Dvořák and Holst excerpts, the drop-off from full forces leads to a reduced texture featuring a single instrumental family plus a solo instrument: the Dvořák excerpt reduces to a sustained chord in the brass with the theme in the oboe, whereas the Holst excerpt drops off to a dissonant harmony held in the strings with the theme scored in the harp. In the Bruckner excerpt, several threads from the preceding material before the drop-off return scored instruments from the string, woodwind, and brass families in reduced form. In layer 1, the melody featuring a duplet-plus-triplet rhythm originally in the woodwind family recurs in a slightly altered form in the flute. In layer 2, the descending chromatic four-note motive in the cello and bass returns in diminution in the same instruments. In layer 3, the dotted rhythmic pattern of the brass returns in the trumpets. Reorchestrations will test the effect of adjustments that transfer the layers into a single family to examine the reasoning behind Bruckner's orchestration choices.

Appendices B4-B6 contain the three reorchestrations of measures 248-268 scored for the string, woodwind, and brass families, respectively. Tables 4-1, 4-2, and 4-3 below outline the adjustments. The timpani roll is held constant in all three versions. The doubling of the timpani by the viola *tremolando* that begins in measure 254 is hereafter referred to as layer 4. In terms of the playback, the slight intonation issue in the trumpets from the original recording was recreated for layer 3 in all versions.

Reorchestrating the versions for each family was not a simple one-to-one transfer. Each adjustment resulted in consequences that affected the audibility and integrity of each layer.[10] These issues are discussed further below.

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[10] I would like to thank Félix Baril for his helpful suggestions to improve the ecological validity of the reorchestrations.

In the string version (see Table 4-1), layer 2 remains the same, but layer 1 transfers to the violin and layer 3 transfers to violin 2 divisi. These adjustments caused several issues. Violin 1 has a lower intensity than the original flute in the same range. Additionally, the violin 2 divisi is extremely weak and difficult to hear, even with a faster attack speed and increased bow noise applied to the playback. As a result, the string version is much less convincing compared to the original; the four layers are difficult to distinguish and the level of overall intensity is reduced.

Table 4-1. String section reorchestration adjustments

Measures	Layer	Original	New	Notes
249-262	1	Flute	Violin	Less intense than original
249-262	2	Cello and bass	Same	
254-262	3	Trumpet divisi	Violin 2 divisi	Faster attack speed, increased bow noise
254-262	4	Viola	Same	

In the woodwind version (see Table 4-2), layer 1 remains the same, but layer 2 transfers to the bassoon and contrabassoon. In an earlier trial, layer 4 was transferred to the clarinet part, but it was completely masked in the mixture. Although not technically a woodwind, the horn is selected instead, thereby creating a better base layer and replicating a standard horn and timpani pairing. Since a real horn player cannot sustain the 8.5 measure pedal point, the note passes smoothly between pairs of horns. In layer 3, the oboe contrasts well with the horn, which is more strident than the original trumpet. Overall, the woodwind version is the most effective out of the three reorchestrations.

Table 4-2. Woodwind section reorchestration adjustments

Measures	Layer	Original	New	Notes
249-262	1	Flute	Same	
249-262	2	Cello and bass	Bassoon and contrabassoon	
254-262	3	Trumpet divisi	Oboe 1 and 2	
254-262	4	Viola	~~Clarinet~~ Horn	Clarinet initially chosen, but horn better as base layer.

In the brass version (see Table 4-3), there were several issues related to instrument range. Layer 1 in the trumpet must be played an octave lower, reducing the ambitus between the highest and lowest parts. Although the trumpet maintains the tension of the original flute, the overall range of the parts is reduced, interfering with layers 3 and 4 in terms of the frequency content. Therefore, the original trumpet divisi of layer 3 is transferred to the horn. The clarity of the motives is also problematic. Layer 2 in the trombone and tuba muffles the chromatic descent. In layer 3, the unison scoring diminishes the dramatic impact of the rhythmic motive.

Table 4-3. Brass section reorchestration adjustments

Measures	Layer	Original	New	Notes
249-262	1	Flute	Trumpet	Lower octave. Removed upper G on downbeat (did not blend)
249-262	2	Cello and bass	Trombone and tuba	
254-262	3	Trumpet divisi	~~Same~~ Horn (unison)	Trumpet could not be heard over other trumpet melody, horn chosen instead. Unison chosen because high C out of range
254-262	4	Viola	Horn	

Based on the reorchestration tests, I argue that Bruckner's aim in the original version is for the three layers to be segregated by listeners into separate auditory streams, as the layers are separated by register and timbral differences.[11] Attempting to score these layers within a single family creates problems related to auditory masking interference. In the other sudden reduction examples discussed above, orchestration is used to highlight the dramatic change from full forces to a smaller subset, but also to separate the foreground and background parts (e.g., chords in background and the melody in the foreground). In this example, Bruckner's goal is to emphasize the structural

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[11] The influence of timbre on auditory stream segregation is discussed further in Chapter 1 (Singh and Bregman 1997; Iverson 1995; Bey and McAdams 2003).

juncture by drawing a connection between the prior presentations of the motives in the full texture and their recurrence in the reduced texture. The reorchestrations eliminate timbral connections to the previous material and weaken the effect of the sudden reduction gesture. Therefore, Bruckner's orchestration promotes the connection to the individual layers and maximizes the effect of the sudden reduction.

Theoretical Implications

The Bruckner case study demonstrates the utility of recompositions and reorchestrations as an analytical tool. The method proposed here allows researchers to test various hypotheses by composing alternative versions through individual adjustments, to conduct comparative listening, and to evaluate the results of the adjustments. The realistic playback of the DOSim renderings immediately brings the recompositions and reorchestrations to life. Insights into the musical features under investigation are revealed not only in the evaluation phase, but also through the act of decision making to create convincing recompositions or reorchestrations and the issues that arise in this process.

The case study reveals several theoretical implications for the sudden reduction gesture. First, the distinction between the deceptive and evaded types was clarified. Both types feature discontinuity at the core but are not interchangeable. In the Bruckner excerpt, the deceptive sudden reduction featured the conflict of triumph turned to defeat at the point of structural breakdown. By removing the point of arrival (i.e., the moment of triumph), the ensuing material became disconnected. Therefore, the surrounding context is crucial for understanding the effect of the sudden reduction. In future work, I plan to recompose evaded sudden reduction excerpts, such as the Mussorgsky/Ravel example from *Pictures at an Exhibition*, to resemble a deceptive type in order to further explore the effects of this change.

Second, the recomposition to remove the tonal instability completely reduced the effect of the sudden reduction. The material after the drop-off emerged as a series of codettas, rather than as a direct consequence of a structural rupture. In effect, the recomposition changed the sudden reduction gesture into a simple sectional division marked by a change of orchestration. The sense of discontinuity and rupture was lost. Further recompositions could investigate whether an increase in tonal ambiguity amplifies the effect.

Finally, the three reorchestrations were created to explore the effect of adjustments that transfer the layers into a single family. The string section version was less tense and did not provide a strong contrast from the previous section. The brass version was especially challenging and required many accommodations due to the limitations of the instruments. The woodwind version was the most convincing, particularly with the strident oboe for layer 1. In all reorchestrated versions, the direct connections to the previous thematic statements were lost. Most importantly, the issues related to auditory streaming revealed the reasoning behind Bruckner's choices in terms of instrumental range and timbre.

In all three cases, I have reached the evaluation stage of the hypothesis testing process of the recompositions and reorchestrations. I have been able to draw some insight into the sudden reduction gesture under investigation; however, further refinement of the hypotheses is needed, which would require additional recompositions and reorchestrations of the Bruckner example, as well as other examples. In future work, I plan to apply the hypothesis-testing method to investigate the function of the anticipatory signal in the sudden addition gestures. I will also examine the role of performance timing and dynamics, which could also be studied using DOSim renderings. In the following section, the hypothesis-testing method of recomposition is applied on a large-scale level. Expert reorchestrations were created to test a hypothesis related to the connection between orchestral brightness and affect. I evaluate the results of the reorchestration process discuss the implications of the new versions.

BRIGHTENING AND DARKENING

Background

As a multidimensional phenomenon, timbre is a complex musical parameter. Studies on the acoustical correlates of perceptual dimensions of timbre have found a robust connection between perceived brightness and spectral centroid, which corresponds to the center of gravity of the relative weights of the frequencies present (McAdams 2013). Timbral brightness is a relevant attribute in orchestration in its connection to orchestral blend (Sandell 1995; Kendall and Carterette 1993), and has been found to be connected to the affective character of instrumental timbre in orchestration treatises and empirical studies.

Orchestration treatises attribute connections between the affective qualities of instruments (or groups of instruments) and their brightness or darkness.[12] These connections can be interpreted within the dimensional model of emotion, in which emotions are understood as involving varying degrees of activity along two indpendent neurophysiological systems related to arousal (low to high) and valence (negative to positive) (Russell 1980; Schubert 2004). Common associations include brightness and positively valenced emotions, as well as darkness and negatively valenced emotions, such as the bright and heroic register of the French horn (Adler 2002, 316), and the somber, dark, and sonorous harp in the low register (Adler 2002, 92). Rather than a strict dichotomy, an interaction with arousal is also evident; piercing, bright timbres are also connected to anger (i.e., high arousal and negative valence) (Kennan and Grantham 2002, 90), and dark or warm timbres are associated with sonorous and mellow affects (i.e., low arousal and positive valence) (Adler 2002, 92).

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[12] This connection is explored further in the companion paper: (Goodchild et al. 2016) [Chapter 5].

Evidence from empirical research also points to a similar association between instrumental timbre and affective character. In many studies, happiness and anger (both high arousal emotions) were associated with bright and sharp timbres, whereas sadness and tenderness (both low arousal emotions) were associated with dull and soft timbres (Juslin 2000; Gabrielsson and Juslin 1996; Eerola, Ferrer, and Alluri 2012).

It is unclear, however, what would happen if the brightness or darkness were increased, while keeping all other musical parameters constant. Would brighter versions augment the high arousal emotions to the extremes along the valence dimension? Would darker versions augment the response the low arousal emotions to the extremes along the valence dimension as shown with the grey arrows? A study design that systematically manipulates spectral centroid would assist in understanding its connection to the valence of emotional experiences.

The hypothesis-testing method of reorchestration provides a unique opportunity to study the effect of brightening or darkening passages on the emotional responses. Therefore, the exploratory question is to investigate the effects of independently modifying the instrumentation to adjust the spectral centroid (i.e., the brightness of the excerpts) keeping all other musical parameters constant. In this section, I will first outline the procedure to create expert reorchestrations of three excerpts creating new dark and bright versions. Next, I will analyze the scores of the reorchestrations and conduct comparative listening of the original and new versions. Through this process, I will evaluate the various strategies of the reorchestrations, the effects of the adjustments in specific musical contexts, and the music-theoretical implications of the alternative versions. In a companion paper, the reorchestration hypothesis-testing method is taken a step further: the comparative listening and evaluation process involves a listening experiment in order to investigate the effect of instrumentation adjustments related to brightness on the emotional quality of the music as felt by listeners.[13]

Reorchestration Method

Overview

The research team (Professor Stephen McAdams, undergraduate student Jamie Webber, and the author) developed this project to investigate the effects of adjusting the brightness or darkness of specific passages while controlling for other musical parameters.[14] Our aim was to document the process of reorchestration, to investigate the music-theoretical implications, and to test the emotional responses of the reorchestrations in a listening experiment (reported in the companion paper).

The research team selected three excerpts (see Table 4-4) featuring dramatic orchestral gestures, which had been found to elicit strong emotional responses in a previous listening experiment.[15] The excerpts featured different orchestration challenges that could potentially require different solutions. Detailed music-theoretical analyses of these excerpts can be found in a prior study.[16] New reorchestrated versions were created by adjusting the instrumentation to globally brighten and darken the excerpts by increasing and decreasing the spectral centroid, respectively.

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[13] (Goodchild et al. 2016) [Chapter 5].

[14] This project was initiated by the undergraduate research project of Jamie Webber during the 2013-2014 academic year.

[15] (Goodchild, Wild, and McAdams 2016) [Chapter 3].

[16] (Goodchild 2016a) [Chapter 2].

Table 4-4. List of excerpts used for reorchestration study, the original recording from which DOSim interpretation is based, and the composer assigned to reorchestrate the excerpt

Type	Composer	Piece	mm.	Recording	Assigned
Gradual Addition	Claude Debussy	*La Mer*, I (1905)	122-141	Berliner Philharmoniker, conducted by Sir Simon Rattle, EMI Classics, 2005	Bouliane
Sudden Addition	Ralph Vaughan Williams	*London Symphony*, I (1914)	8-53	Royal Liverpool Philharmonic Orchestra, conducted by Vernon Handley, EMI Classics, 2011	Baril
Sudden Reduction	Gustav Holst	*The Planets*, "Uranus" (1916)	193-236	London Philharmonic, conducted by Sir Adrian Boult, EMI Classics, 2002	Rea

Reorchestration process

Given the complexity of the reorchestration task, the research team approached three professional composers: Professor John Rea, Professor Denys Bouliane, and composition PhD candidate Félix Frédéric Baril from the Schulich School of Music, McGill University. In the first stage (lasting approximately 3 months), the scores were input into the notation software Finale (Make Music) and realistic renderings were created using DOSim, a process led by Bouliane and Baril. The performance interpretations of the beat-to-beat tempo changes and global dynamic levels were matched to recordings (listed in Table 4-4 above).

In the second stage, the composers were assigned to a particular excerpt (see Table 4-4) and asked to experiment with adjustments of instrumentation in order to achieve the target effect related to augmenting the brightness or darkness. All three composers created the reorchestrations in Finale and could instantly hear realistic playback from DOSim during this process. The performance interpretations were held constant across versions.

The most challenging aspect of this stage of the research project was operationalizing the concept of brightness. The composers expressed their personal understanding of brightness differently. Given the novel nature of this reorchestration task, the research team and composers met several times to discuss the conceptualization of brightness and darkness (discussed further below).

Several guidelines and restrictions were decided upon for executing the task. First, the new version must be playable by a real orchestra. In other words, synthesized sounds or instruments playing out of range would not be possible. Second, the style and character of the original version should be preserved, and the reorchestrations should be believable. Finally, the overall pitch range and textural density should be comparable, with the aim of shifting the spectral weight. Although octave transpositions were possible, the aim was not to create a version that was simply globally transposed by a certain interval.

After approximately three months, drafts of the reorchestrations and their renderings were evaluated by the research team and composers. Several modifications were suggested in order to ensure that the changes were audible, yet still reflected the original style. The final versions were completed two months later.

Post-project interviews

The author and Jamie Webber performed semi-structured interviews with each of the composers to receive feedback about their experiences with the reorchestration task. The framework of the questions is listed in Table 4-5 below. The general responses to the questions will be discussed presently, but piece-specific details will be discussed below.

Table 4-5. Post-project semi-structured interview questions

1. Have you created reorchestrations like this before? How does this task differ from other reorchestrations you have created?
2. How did you conceptualize brightness or darkness?
3. Did you have any specific sonic goals in mind? Explain.
4. Could you outline the types of experimentation that you performed before finalizing the version?
5. What were some particular challenges of the excerpt? Did you find the task difficult?
6. What technique or adjustment did you find to be the most effective?
7. Which versions were most effective or successful?

None of the composers had created reorchestrations to adjust the brightness or darkness in their previous work. Bouliane explained that re-arrangements are extremely common. Composers are often involved with creating piano reductions, transcribing from piano to orchestra, or orchestrating for different ensembles. Rea, for example, has been commissioned to create reorchestrations, such as a chamber version of Berg's *Wozzeck* for 21 players (Denesiuk 2015). However, the composers had never attempted a reorchestration with the goal of changing the brightness in a systematic way.

When asked, the composers explained their conceptualization of brightness in direct relation to the musical context of the excerpt. Bouliane noted that the idea of brightness and darkness can be elusive: it can be understood in terms of the technical quality of instrumental timbre(s), but also in terms of how the music is experienced. Turning to the opening of the Debussy excerpt, Bouliane detailed various options and challenges of adjusting Debussy's scoring, as well as the associated risks of changing the flow, shape, dynamics, and textural features of the original. He described the bright version of the Debussy excerpt as somewhat lighter and the dark version as heavier, although the shape and function of the orchestral swells and climaxes still function as in the original.

Baril conceptualized changing the brightness in terms of rebalancing and adjusting the weighting of instruments in the Vaughan Williams excerpt. Baril noted that the original version contained a lot of doublings, which allowed him to play with the weighting of parts. He detailed his process of experimentation, which involved re-imagining each line and rebalancing to make it brighter or darker.

Rea explained that the Holst excerpt was particularly challenging to reorchestrate because the original version was already very bright, leaving little room to brighten further. He explained that the entire ambitus is covered, bounded by two poles—the double basses are scored at the lower limit of C_2 and the piccolo covers the high limit of C_6. Holst privileges the upper, bright part of the range, resulting in what Rea called a “white heat” or total saturation. Given that there are limited additional instruments available, Rea needed to give the impression of increased brightness by re-voicing chords and adding more weight to certain scale degrees. To darken, Rea removed key instruments focusing on the upper part of the range (e.g., the bright spectra of horns). He explained that his basic principle involved shifting certain parts by octaves. He defended his use of octave transposition, as the themes remain recognizable played in different registers.

Baril and Bouliane provided details of their process of experimentation for their reorchestrations. Baril found that he needed to tone down initial attempts. For example, he initially added a contrabassoon to double a bassoon part, but he felt that it added too much weight and changed the flow of the line. Bouliane’s approach involved changing individual lines first and then observing how each line complimented the other lines. Through this process, he tried many different possibilities. In his initial draft of the bright version, Bouliane aimed to maximize the difference from the original version; however, the research team and composers found it to be too extreme, so he reduced some of the adjustments in the final version.

Analysis of brightened and darkened versions

Overview

This section provides an analysis of the bright and dark reorchestrations for each excerpt. The full scores of the dark and bright reorchestrations can be found in Appendices C1-C6 and the sound files can be streamed from the supplementary material.[17] To compare across excerpts, I examine short segments featuring specific types of textures: full forces, reduced texture, and transitional (moving between reduced and full). I will describe common strategies employed by the

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[17] http://sites.music.mcgill.ca/orchestration/projects/dosim-reorchestration/

three composers, as well as unique solutions for particular situations. This discussion will also incorporate interview responses.

I developed a method to annotate the adjustments of the bright and dark versions. The legend for the symbols is presented in Table 4-6. The symbol references the manner in which the new version has been changed in relation to the original. Symbols are applied to the first note of each part and last until the next symbol. The equal sign designates that the instrumental line is scored at the same pitch as the original. A straight arrow pointing up or down indicates that the instrumental part has been transposed up or down an octave, respectively. The curved arrow with one arrowhead designates that the instrumental line has been doubled, pointing from the original instrument to the doubling instrument. If the curved arrow is used with a straight up or down arrow, the doubling occurs at the upper or lower octave, respectively. A circle indicates that the original instrumental part has been removed. The circle is also used in conjunction with the curved arrow, which indicates that the part has been transferred to another instrument. The curved arrow (with two arrowheads) represents re-voicing divisi intervals, such as thirds inverted to sixths, or vice versa. The curved arrow can be used with an up or down arrow to show that the inversion has resulted in a shift of a part up or down an octave. A square box highlights a change in playing technique, such as adding mutes or harmonics. An asterisk indicates that a new line has been added that was not in the original. Finally, the up or down arrow with "X2" indicates that the part has been shifted up or down by two octaves.

Table 4-6. Legend for annotation symbols used to analyze the bright and dark versions

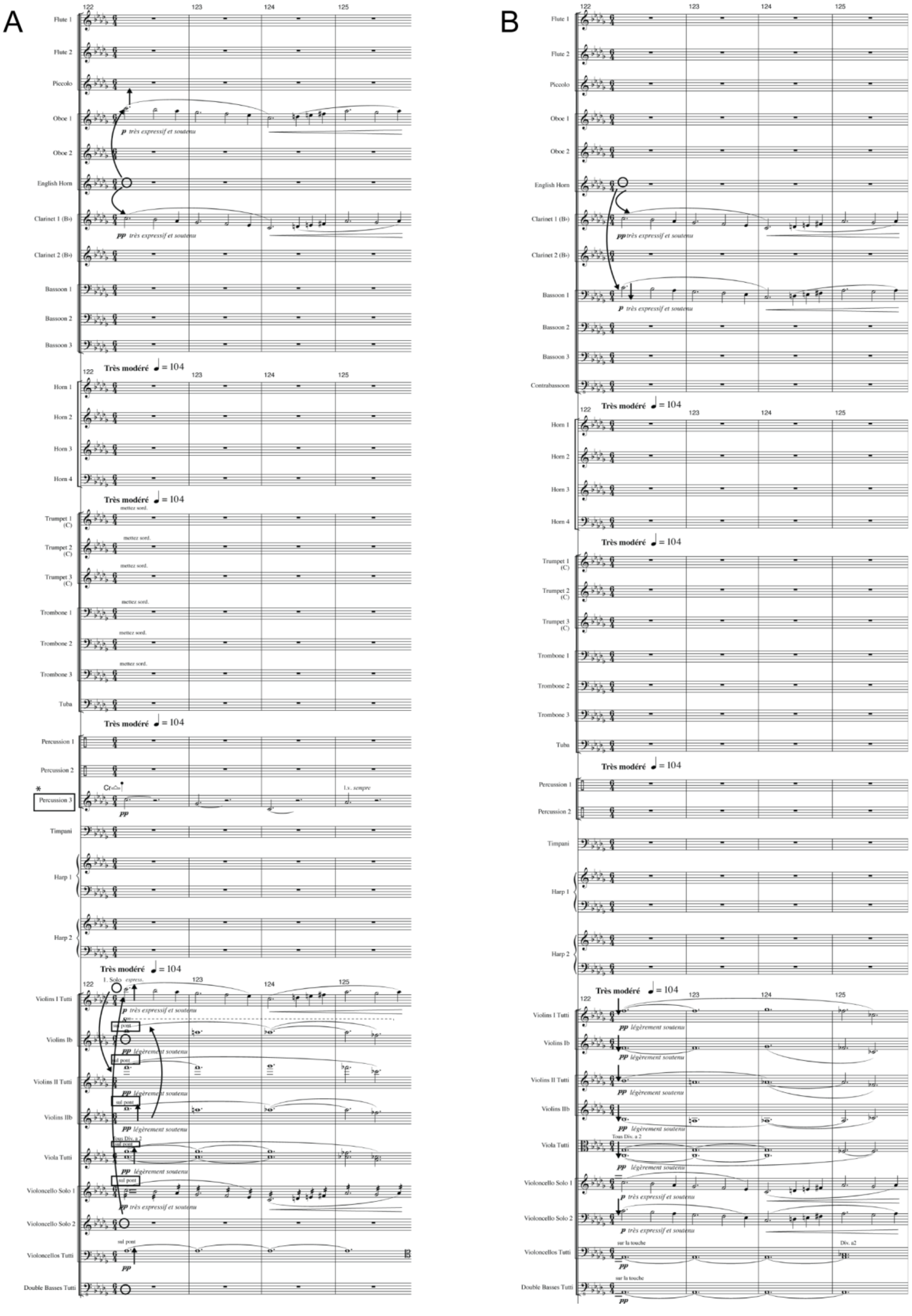
Symbol	Explanation
=	Part at the same pitch as original
↑	Part shifted up (or down) one octave
↷	Line doubled or transferred to another instrument
○	Original part removed/transferred
⇅	Used for revoicing divisi intervals (e.g., thirds inverted to sixths)
□	Change in playing technique added (e.g., mutes)
*	New line added
↑x2	Part shifted up (or down) two octaves.

Debussy excerpt

The Debussy excerpt features a gradual addition orchestral gesture that concludes the first movement of *La Mer*. The excerpt is divided into three sections that build in intensity. I will analyze the bright and dark versions (Appendices C1 and C2) for three segments from the three sections: the opening with stratified melody and string accompaniment (mm. 122-127), the transition (mm. 132-133), and the ending with full forces (mm. 136-137).

For the opening section of the bright version (Example 4-1A), Bouliane focuses on the main melody of the English horn, which has a very strong first harmonic an octave above the written pitch. To recreate the English horn with a brighter timbre, he scores the clarinet at pitch and an oboe an octave higher. Additionally, one of the solo celli plays *tremolando*, causing the bow to cross the bridge more rapidly. Bouliane explains that the *tremolando* creates a shimmering, brittle sound. He brightens the other solo cello along with the other strings by adding the technique of *sul ponticello*, which brings the bow closer to the bridge, dampening the lower partials and privileging the upper partials. He describes the effect as a high-pass filter creating a metallic sound. Another new technique is the addition of the crotales on the downbeat for an emphasis in colouring. Bouliane was inspired to add these "touches of brightness" based on Debussy's similar usage using the glockenspiel in *Prélude à l'après-midi d'un faune*. For the background string section, Bouliane re-voices the chord and shifts the parts up by an octave.

In the opening section of the dark version (Example 4-1B), Bouliane transfers the English horn part into the bassoon, which has a similar character and spectrum as a double reed. He explains that the bassoon an octave lower than the English horn will actually sound only slightly lower. To give the impression of the English horn in spirit, Bouliane includes the clarinet as a subtle way to add the emphasis on the second partial of the bassoon's pitch. He keeps one cello at pitch and doubles the second cello an octave lower. The rest of the strings are shifted down an octave, excerpt for the bass. He notes that it was important that he maintain the original voice-leading and the impression of the span of the chords, although the range is compressed. Bouliane views the dark version to be darker and slightly warmer, noting that the frequencies in close proximity seem to "boil together."



Example 4-1. Bright (A) and dark (B) reorchestrations of Debussy excerpt, mm. 122-125

In the transition section for the bright version (Example 4-2A), Bouliane adjusts parts in several ways to increase the brightness with the available resources. For the arpeggio pattern, flute 2 is transferred into the piccolo part, doubling the flute one octave above, along with the crotales. Bouliane explains that he adds *sordino* (mute) to the ascending line in trombone 3, to deemphasize the fundamental frequency and to enhance the higher partials. He also brightens the line by doubling with the horn with a hand stop. The triplet motive in the bassoons and horns is re-voiced and changed in several ways: horn 1 is transferred into oboe 2 an octave higher, horn 3 is transferred to trumpet 3 with *sordino,* and horn 2 adds harmonics. In measure 133, the neighbor-note figure in trombones 1-3 are transferred into trumpets 2 and 3 with *sordino*. Although the bassoons play an octave higher, the horns continue with the harmonics at the original pitch. Bouliane also adjusts the size of the cymbal from medium to small, which changes the character of the noise added.

In the transition section for the dark version (Example 4-2B), Bouliane explains the need for more radical changes in addition to shifting down an octave. Flute 2 is transferred into English horn (doubling at one octave below), which Bouliane believes draws the listener's attention to the lower frequencies. The ascending line in trombone 3 is transferred down an octave into the tuba. Similarly, horn 2 is transferred into trombone 1, and bassoon 3 is transferred into the contrabassoon at the lower octave. The cymbal size is changed to large as well.

Example 4-2. Bright (A) and dark (B) reorchestrations of Debussy excerpt, mm. 132-133

For the full forces segment from the final section of the bright version (Example 4-3A), Bouliane continues to adjust part by part to achieve a brighter effect. The triplet line in the woodwinds is reinforced in the xylophone and in the piccolo an octave higher, a change that Bouliane describes as an "extra punch." Additionally, the flute 1 melody is slightly changed, with notes kept at the original pitch and some shifted an octave higher. Bouliane clarifies that this balancing of the ranges is not noticeable as the overall contour is retained. For the brass section, he explains that he cannot transpose the trumpet an octave higher because the extreme of its range would sound too much like screaming. As a compromise, he re-voices the brass so that the oboes take the lines of trumpets 1 and 2. He notes that although it cannot replicate the strength of the trumpet, the high range of the oboe will augment the intensity. The horns play at pitch with stops, thereby changing the colour but also diminishing the volume. Bouliane notes that he added more weight in other parts, such as incorporating the English horn, to compensate for this.

In the dark version (Example 4-3B), most parts are shifted down an octave or kept at pitch. Bouliane notes that the harp transposed down an octave produces a darker colour, but does not sound as dramatic as the same transposition on the piano. Horn 1 doubles clarinet 2 with the woodwind melody, adding a greater weight to the line.

When asked about the difficulty of making adjustments when all of the forces are engaged, Bouliane answers that he did not find it more challenging. He explains that he conceptualizes the orchestra in terms of families and roles, therefore he considers what he could adapt to reinforce what was lost or changed for each part.

Example 4-3. Bright (A) and dark (B) reorchestrations of Debussy excerpt, mm. 136-137

Vaughan Williams excerpt

The Vaughan Williams excerpt, which begins the first movement of the *London Symphony,* features a sudden addition orchestral gesture. I will analyze the bright and dark versions (Appendices C3 and C4) for three segments: initial sparse string texture (mm. 8-12), the transitional section (mm. 19-28), and the moment of sudden addition with full forces (mm. 39-53).

For the opening string section, Baril keeps the instrumental parts within the strings, which limits his options for adjustments to rebalance the weight of the lines and to adjust the range. Whereas the original version spans five octaves, the bright version expands to six octaves and the dark version compresses to four octaves. Figure 4-4A shows the adjustments made for the bright version for the opening.[18] As discussed above, Baril describes his process as rebalancing the weight of the lines, with some octaves changed to unisons and unisons changed to octaves. For the bright version, the original violin 1 octave doubling (divisi) shifts up one octave. The violin 2 octave doubling (divisi) changes to a unison on the upper octave. The violas begin at pitch, but in measure 9 the original octave doubling is changed to a unison. The original third at measure 11 is inverted to a sixth, with the C transferred to the upper octave. The cello and bass parts are shifted up an octave for measures 8-11. Although the cello maintains the octave divisi at pitch, the lower octave doubling in the bass is dropped at measure 11.

In the dark version (Figure 4-4B), Baril changes the roles of the parts. The viola no longer plays the bass line, thereby shifting the weight into the cello and double basses. In measures 8-9, the violas double the violin line at the lower octave. Additionally, the upper octave of the violin line is removed. In the cello and bass, Baril removes the mutes (*senza sordino*) and adds directions for bowing near the fingerboard (*sul tasto*). He explains that his unconventional idea was to add more emphasis on the fundamental frequency in the bass instruments. As a result, he maintains the same

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[18] Note that the original divisi parts for violins 1 and 2 have been separated into solo and section lines.

number of individual lines, but the colouring and weighting is changed. Some of the contours of the individual instruments are changed with the octave jumps. Baril explains that this adjustment adds more weight and expands the range as a reinforcement of the lines. He notes that the original pitch is still present in another part.

Example 4-4. Bright (A) and dark (B) reorchestrations of Vaughan Williams, mm. 8-12.

The transition section allows for further experimentation with the woodwind and brass families. In addition to octave reinforcement used in the first section, Baril develops new techniques for increasing the brightness (see Figure 4-5A). In the woodwinds, the bassoon melody (which doubles the second horn part) beginning in measure 19 transfers into the English horn mid-phrase in measure 21, which resembles a *Klangfarbenmelodie*-like timbral brightening. Baril explains that he wanted the bassoon to hold the pitch in order to add expression like a timbral melody, as it blends naturally with the horns and double reeds. To make the horn brighter at measure 23, Baril adds a stopping mute (bouché), which produces a nasal sound with many upper harmonics. Beginning in measure 26, horns 2 and 3 are transferred to trumpets 1 and 2 with mutes (*con sordino)*, which also brightens the timbre considerably.

In the dark version of the transition segment (Figure 4-5B), Baril continues to add weight to the lower octaves. In the woodwind section, clarinet 2 is transferred to the lower octave in the bass clarinet in measure 19. In measure 21, the parts in oboes 1 and 2 are transferred into the darker, *chalumeau* register of the clarinet. Additionally, the alto flute is used to reinforce at the lower octave of the flute line. The triad in flutes 1-3 is inverted to transfer the parts into the lower octave at measure 23. Baril notes that the shift of the English horn down an octave in measure 22 into a more resonant register makes a striking difference in his opinion. In the brass, the horn line at measure 22 is transferred to trombone 1 an octave lower. Beginning in measure 27, horns 2 and 3 are moved into trombones 2 and 3; the former is also doubled at the lower octave in the tuba. Therefore, Baril reassigns the parts to instruments with a darker character.

For the full forces segment, Baril explains that the bright version (Figure 4-6A) is very bright, noting that he “pushed everyone.” He mainly uses octave doublings where possible and inverted intervals, as shown with the double-headed arrows. In the percussion section, Baril scores a small cymbal for higher pitched roll. In the dark version (Figure 4-6B), he used a similar strategy with doublings at the lower octave and inverted intervals. The horn and trombone parts were swapped, adding a deeper character to the descending chromatic line. In addition to including the bass drum and large tam-tam, a large cymbal is used for lower-pitched percussion.

Example 4-5. Bright (A) and dark (B) reorchestrations of Vaughan Williams, mm. 19-23.

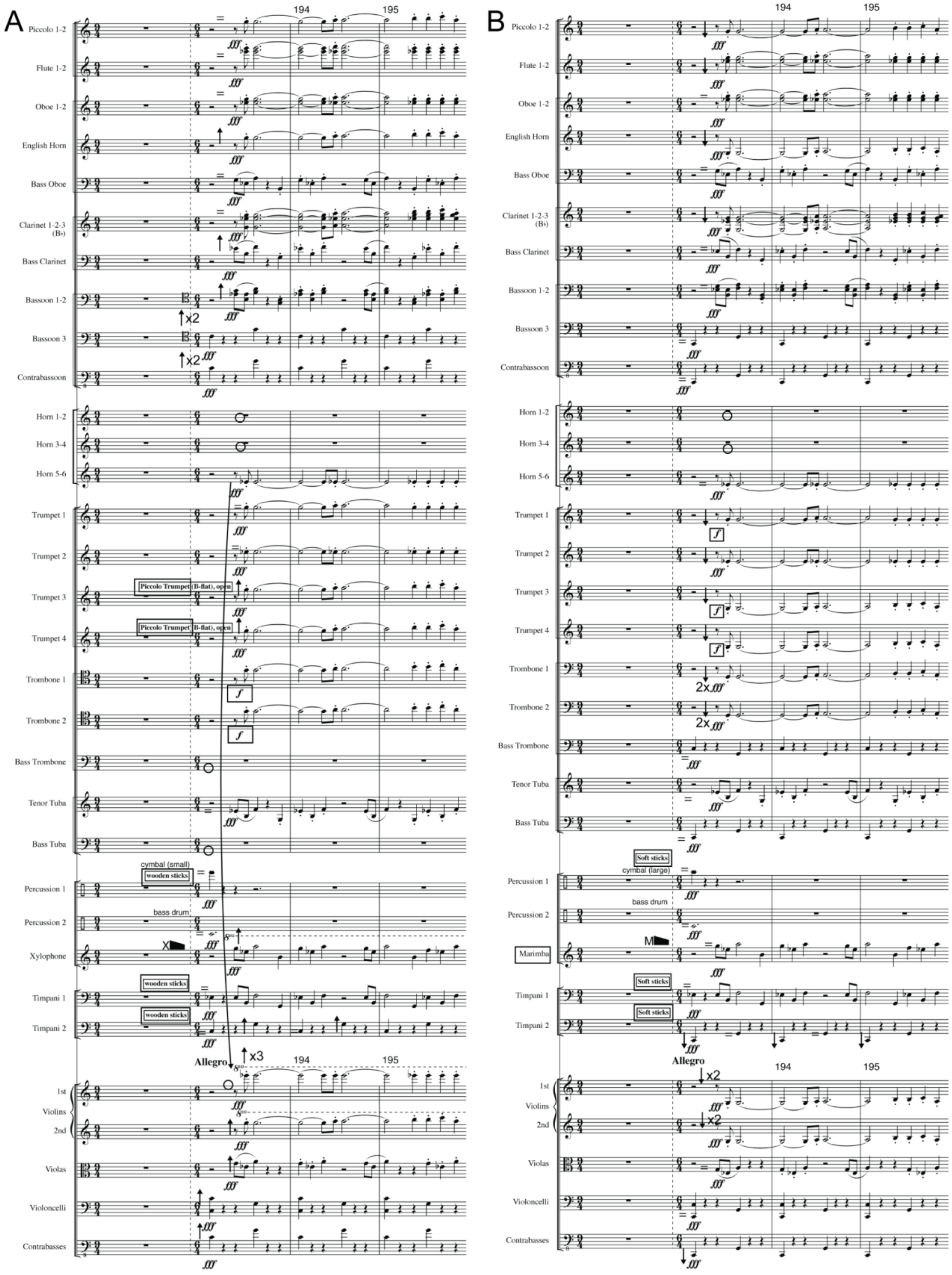
Example 4-6. Bright (A) and dark (B) reorchestrations of Vaughan Williams, mm. 38-41.

Holst excerpt

The Holst excerpt, from the ending of the movement "Uranus: The Magician" from *The Planets,* features a sudden reduction orchestral gesture. For this excerpt, I will analyze the bright and dark versions (Appendices C5 and C6) of a segment from the beginning with full forces (mm. 193-195) and a segment following the drop-off (mm. 222-232). Unlike the other two excerpts, the Holst excerpt features only these two textures (i.e., no transitional segment).

As discussed above, the Holst excerpt was challenging to reorchestrate because the original version was already very bright. Due to the repetitive and static instrumentation, Rea applies the adjustments broadly, which mainly involves shifting parts by an octave, re-voicing the chords, and adding more weight to certain scale degrees. Figure 4-7A shows the adjustments for the full forces section of the bright version. One particularly interesting change involves the transfer of the horn line into the violin three octaves higher. Rea explains that there is already saturation at the lower frequency range, and this adjustment emphasizes the mediant scale degree of the chord rather than the fifth. Rea changes the percussion from medium sticks to wooden sticks to amplify the higher frequencies. In the brass section, Rea uses the piccolo trumpet at the higher octave to increase the brightness. Additionally, he changed the dynamic level of the trombone from *fff* to *f* to reduce the energy in the mid to low range.

As shown in Figure 4-8A, Rea darkens by removing instruments in the upper part of the range, such as the horns with bright spectra, and by shifting the parts down by one or two octaves. The dynamic level of trumpets 1-3 is adjusted from *fff* to *f,* which reduces the energy in the midrange and reduces the energy spread into the upper harmonics. For the percussion, soft sticks are scored, likely to dampen the upper frequencies of the cymbal and timpani. Instead of the xylophone, Rea scores for the marimba, a change which may increase the resonance at the fundamental frequency.



Example 4-7. Bright (A) and dark (B) reorchestrations of Holst excerpt, mm. 193-195.

For the reduced-texture segment after the sudden reduction, Rea maintains the scoring within the string family and the two harps. For the bright version (Figure 4-8A), he shifts the violin divisi up one octave and re-voices the violin 2 and viola lines at measure 222, as well as the viola and cello lines at measure 227. Harp 1 is shifted two octaves higher with the harmonics removed and harp 2 shifts one octave higher. For the dark version (Figure 4-8B), Rea uses similar strategies in the strings: shifting down an octave and re-voicing at measure 227 between the violin 2 and cello. Harp 1 is played at pitch, but the harmonics are removed. In harp 2, the B in the upper clef is omitted, emphasizing the lower intervals of the chord.

Example 4-8. Bright (A) and dark (B) reorchestrations of Holst excerpt, mm. 222-228.

Results of reorchestrations

Summary

The three composers were faced with a novel and challenging task to adjust the brightness and darkness of specific passages of orchestral music. The self-imposed restrictions meant that the adaptations must be playable by a real orchestra and respect the style and character of the original version. The composers developed both common and unique solutions for this task. All three shifted parts up or down by octaves. They doubled parts or transferred parts to instruments within the same family (or, in more extreme cases, to other families) at pitch or adjusted by an octave. Additionally, they changed the size of the percussion instruments: Bouliane and Baril changed the size of the cymbal (small for bright and large for dark) and Rea adjusted the types of mallets and sticks for the cymbal and timpani.

For the Debussy excerpt, Bouliane incorporated particular playing techniques, such as *tremolando* and *ponticello* in the strings and various mutes and harmonics in the brass, in order to highlight or dampen certain frequencies. He also scored for the crotales and glockenspiel in order to add additional brightness. In the Vaughan Williams excerpt, Baril introduced the *sul tasto* technique for the strings and the stopping mute (*bouché*) for the horn, as well as adding and removing the mutes in the brass. He also created a timbral melody by sustaining the bassoon to blend with the other instruments. Rea adjusted the dynamic levels to rebalance the energy in certain frequency ranges in the Holst excerpt.

Comparative listening and evaluation

The comparative listening stage of the hypothesis-testing method is conducted on a large-scale level with an experimental listening study and is reported in a companion paper.[19] The research team and composers also conducted detailed comparative listening to ascertain whether the differences among the versions were audible and appropriate for the group-listening test.

To quantify the adjustments, the time-varying spectral centroid (frequency in Hz) was extracted from the DOSim-rendered excerpts with PsySound3 (Cabrera, Ferguson, and Schubert 2007). Figure 4-2 compares the resulting spectral centroid variation over time of the original and reorchestrated versions rendered by DOSim.[20] Vertical lines indicate the moment of sudden change for the sudden addition of the Vaughan Williams excerpt and the sudden reduction of the Holst excerpt, as well as the large sectional divisions for the gradual addition of the Debussy excerpt. Overall, the new versions maintain the textural density, but shift the spectral weighting. The overall range is compressed or expanded, but not simply transposed globally. The adjustments made by the composers focus on the colouring, balance, and weight of the instrumental parts, reinforcing certain frequency ranges.

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[19] (Goodchild et al. 2016) [Chapter 5].

[20] (Goodchild et al. 2016) [Chapter 5].

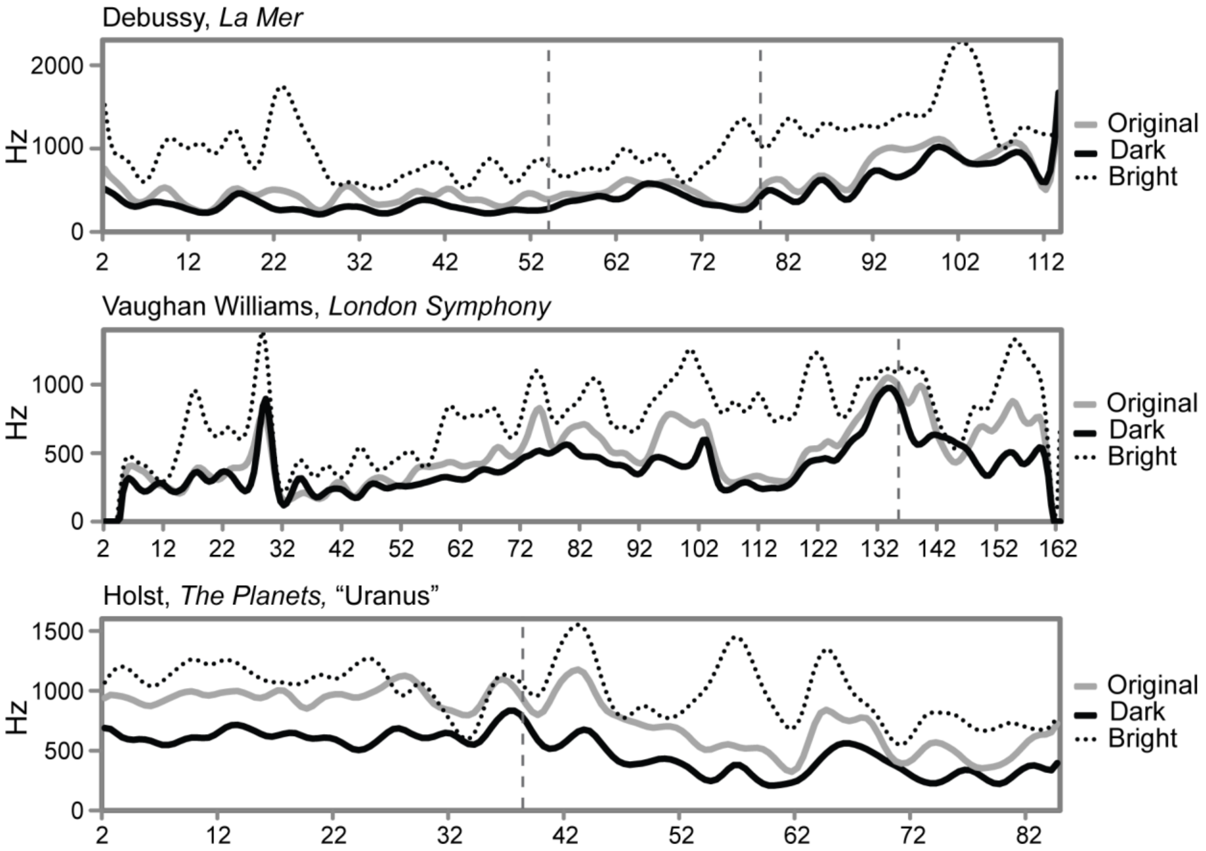

Figure 4-2. Spectral centroid comparison of the three excerpts of the original, dark and bright versions. Vertical lines indicate the segments.

Conclusion and Discussion

In this paper, I presented a hypothesis-testing method of recomposition as a flexible and powerful music-theoretical tool. The method proposed here allows researchers to test various hypotheses by composing alternative versions through individual adjustments, to conduct comparative listening, and to evaluate the results of the adjustments in an attempt to distill an understanding of the essential aspects of the musical feature. The process is not linear, allowing the researcher to adapt and refine the hypotheses or adjustments at various stages. Importantly, the comparative listening step is a crucial aspect that has only been tacit in previous work. This explicit process moves beyond the informal and limited application of recomposition commonly used in the discipline, with the goal of reaching an analytical conclusion and ultimately contributing to the development of knowledge about the musical phenomena under investigation.

I argue that reorchestration as part of the recomposition method should be adopted as an accessible entry point for theorists to engage with timbre and orchestration—a topic which is currently underdeveloped in music-theoretical research. In addition to the evaluation phase, insights about musical phenomena arise through the act of decision making to create convincing recompositions or reorchestrations.

The case study of the sudden reduction gesture in the Bruckner excerpt demonstrated the utility of recomposition and reorchestration as an analytical tool. Additionally, several theoretical implications about the sudden reduction gesture were revealed through the process, including the function of the arrival chord, the role of the tonal instability, and the reasoning behind Bruckner's instrumentation choices related to thematic connections and auditory streaming.

The hypothesis-testing method was employed on a large-scale level to investigate the effect of augmenting the timbral brightness or darkness of excerpts while controlling for other musical parameters related to structure and performance. Initially, the operationalization of brightness was particularly challenging. However, the composers made intuitive adjustments to the instrumentation and experimented with various changes to achieve the desired effect by cycling through the stages of recomposition, comparative listening, and evaluation. Each composer's conceptualization of brightness was made directly in reference to the excerpt at hand, but they employed fascinating strategies to shift the spectral weighting with the available resources without changing the textural density. The aim of the work presented here is to point other researchers in the direction of orchestral gestures as a fruitful area of study, to build on the traditional usage of recomposition with a hypothesis-testing methodology, and to promote collaboration with composers and theorists in the future.

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CHAPTER 5

BRIGHTENING AND DARKENING: BEHAVIOURAL AND PSYCHOPHYSIOLOGICAL RESPONSES TO CHANGES IN ORCHESTRATION

Orchestration treatises contain associations between timbral brightness or darkness and instrumental affect. Recent empirical findings also indicate connections between spectral centroid (the center of gravity of the spectrum with robust connections to perceived brightness) and perceived emotional valence. Given the difficulty in studying this phenomenon across musical contexts, expert reorchestrations were created in Chapter 4 to vary the spectral centroid through individual adjustments in instrumentation while keeping constant musical features related to performance expression (timing and dynamic variation) and structure (harmony, melody, rhythm). Chapter 5 reports the results of a large-scale experiment in which subjective (arousal and valence responses) and objective (biosensor) measures were recorded continuously while participants listened to original and reorchestrated versions. Activity analysis, a new type of analytical approach, is used to investigate response coordination and areas of high activity for measures of arousal and valence across the original, bright, and dark versions. The chapter seeks to investigate the link between timbral brightness and felt emotional responses and to contribute to orchestration theory and music and emotion research.

This chapter is based on the following research article:

Goodchild, M., Beauregard Cazabon, D., Webber, J., Wild., J., and S., McAdams. "Brightening and Darkening: Behavioural and Psychophysiological Responses to Changes in Orchestration." Manuscript prepared for submission.

ABSTRACT

Orchestration treatises contain associations between the brightness of instrument timbres and emotional qualities, but these informal accounts do not fully consider musical contexts or the relationships between the instrumentation and other musical parameters. Recent research reports an association between the brightness or darkness of instrumental timbres and affect. However, there are inconsistent predictions for the role of spectral centroid, a measure of brightness, in instrumental ensembles on emotional responses in the music and emotion literature. This paper investigates the connection between orchestral brightness and its effect on the valence of felt emotional responses. Spectral centroid was modified independently through adjustments in instrumentation to explore its interaction with other musical parameters and to investigate its effect on felt emotional responses. With composers John Rea, Denys Bouliane, and Félix Frédéric Baril, we created reorchestrations of three excerpts to produce four new versions: brightened, darkened and two hybrid combinations (dark-to-bright and bright-to-dark). Using the Digital Orchestra Simulator (DOSim), we created realistic acoustical renderings of the originals and the reorchestrations. Performance timings and dynamic variations, based on real recordings, remained constant across versions. In group-listening sessions, both behavioural (continuous ratings of arousal and valence) and psychophysiological (biosensor) measures were collected for 108 participants (between-subjects design).

Whereas the arousal measures were mainly invariant to changes in orchestration, the valence measures differed for brightened and darkened versions, although not always in the predicted direction. Comparing responses to the hybrid recombinations (e.g., bright-to-dark vs. globally dark versions) reveals that the responses to the same passage of music are influenced by the preceding context in certain cases. Overall, we draw connections between changes in timbral brightness and emotional responses, highlight relationships between perceptual and musical dimensions, and suggest ways that these findings could be incorporated into a perceptually based theory of orchestration.

INTRODUCTION

Orchestration and timbral changes are known to influence the perception of form, contribute to the creation of musical tension, and elicit emotional responses in listeners (McAdams 2013). However, the study of timbre in music research is underdeveloped, with few theories to explain instrumental combinations (Boulez 1987; Sandell 1995; Slawson 1985). Given that timbre is a multidimensional phenomenon, theories of orchestration grounded in perception must account not only for complex interactions of many factors related to timbre, but also for its interactions with other musical parameters, such as pitch, harmony, and dynamics. One potential starting point for inquiry is the often-cited correlation between spectral centroid (calculated as the center of mass of the frequency spectrum) and the perceived brightness of a sound (McAdams 2013). Instruments with more energy in the upper harmonics will have a brighter or more nasal sound (e.g., oboe) compared to instruments with more energy in the lower partials with a darker tone (e.g., trombone) on the same pitch (McAdams 2013, 41). In relation to orchestration, timbral brightness has been found to be connected to an instrument's ability to blend with other instruments (Sandell 1995; Kendall and Carterette 1993) and to its affective character.

Orchestration treatises attribute associations between the emotional qualities of instruments (or groups of instruments) and their perceived brightness or darkness. These associations can be interpreted within the dimensional model of emotion, in which emotions are understood as involving varying degrees of activity along two indpendent neurophysiological systems related to valence (negative to positive) and arousal (low to high).[1] In treatises, bright timbres are associated with high arousal emotions of both positive and negative valence. For example, Adler (2002) provides descriptions of bright timbres with positive affective qualities, such as the bright and heroic register of the French horn (at pitches C_4 to G_5) (316), and the bright and full brass creating an atmosphere of celebration (375). Kennan and Grantham (2002, 90) describe the shrillness of the clarinet in the upper register used in grotesque and unpleasant effects (bright timbre with negative affective quality). In contrast, dark timbres are associated with low arousal emotions of both positive and negative affect. Adler (2002, 92) describes the somber, dark, and sonorous harp in the low register, and the dark and foreboding lower range of the bassoon (dark timbres with negative affective quality). Similarly, Berlioz (MacDonald [1855] 2002) describes both positive and negative affect for the clarinet in the low range: "the medium and *chalumeau* registers are suited to cantabile melodies, arpeggios and runs. The low register, especially in sustained notes, produces those coldly threatening effects, those dark accents of quiet rage which Weber so ingeniously invented" (206).

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[1] The dimensional model was influenced by Russell's (1980) circumplex model, in which valence was originally conceptualized as a continuum of pleasure-displeasure. More recently, researchers have avoided applying terms to the valence dimension that imply feelings of pleasure and displeasure, particularly given the issue that listeners may enjoy listening to music that is sad or negatively valenced (Schubert 1999, 104).

Empirical research on isolated timbres has also reported a similar connection between timbral brightness and affective character. Hailstone et al. (2009) investigated the relationship between sound identity and emotional content. Novel melodies were composed to represent four specific emotions (happiness, sadness, fear, or anger) and recorded on four instruments (synthesizer, piano, violin, or trumpet), controlling for parameters of loudness and tempo. They found a significant interaction between instrument and judgment of intended emotional expression. For happy melodies, the probability of an intended response was lower for the violin compared to other instruments. For sad melodies, the odds were lower for the synthesizer. For angry melodies, the odds were lower for the trumpet. In a second experiment using unfamiliar synthesized timbres, they replicated the finding that the perception of melodies was affected by musical timbre, independent of other musical features. Anger was better identified using timbres with strong high frequencies and notched spectral envelope, whereas sadness was better identified by strong middle and low frequencies.

In Juslin and Timmers's (2010) summary of the research on emotion communication in performance, they report that performers convey the five basic emotions (happiness, tenderness, anger, fear, and sadness) through various acoustic cues, including tempo, sound level, timing, intonation, articulation, vibrato, tone attacks, tone decays, pauses, and timbre. In terms of timbre, performers use cues related to the brightness of the timbre for emotional communication. Happiness and anger (both high arousal emotions) were associated with bright or sharp timbres, whereas sadness and tenderness (both low arousal emotions) were associated with dull or soft timbres (Juslin 2000; Gabrielsson and Juslin 1996). Therefore, performance cues related to the brightness of the timbre were found to influence emotional qualities in combination with other performance cues, especially those related to arousal.

Several studies have shown evidence of spectral centroid as a factor in emotional vocal expression and music performance. Juslin and Laukka's (2003) large review study indicated several connections between the acoustic factors in music and speech that convey emotions, including timbral parameters related to an instrument's spectral energy. Cross-modal patterns of acoustic cues for discrete emotions related to timbre included medium high-frequency energy for happiness, high-frequency energy for anger, and little high-frequency energy for sadness and tenderness. Along these lines, Huron, Anderson, and Shanahan's (2014) correlational questionnaire study tested the hypothesis that instruments judged to be capable of expressing sadness would also exhibit acoustic features similar to speech that conveys sadness. The darkness of the timbre was found to be one of the features correlated with an instrument's capacity to produce a sad sound.[2]

Eerola, Ferrer, and Alluri (2012) investigated the role of instrumental timbre in the perception of dimensions of affect. Spectral (e.g., spectral centroid, spectral spread), temporal (e.g., attack slope, envelope fluctuation) and spectrotemporal (e.g., spectral flux) dimensions—which have been found to be salient in previous studies relating to expressive content of music and speech (described above)—were used to predict participants' affective evaluations of single instrument sounds. Listeners were able to evaluate consistently the affective qualities of the brief, isolated sound samples. Given that the stimuli did not vary in terms of pitch, dynamics, melody, or harmony, the results indicate the importance of timbre in emotion perception. Instruments that were high in positive valence were found to contain more energy in the lower frequencies rather than the higher frequencies, which would suggest a lower spectral centroid. The authors called for further research on the effect of orchestration on affect by making empirical evaluations of instrument combinations.

Spectral centroid can also be calculated on large instrumental ensembles based on the composite of the individual timbres. Emery Schubert (2004) performed a time series regression

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[2] Issues with the experimental design of this paper are discussed by Vuoskoski (2014).

study to investigate the relationship between time-varying musical features (loudness, tempo, melodic contour, instrumental texture, and spectral centroid) and continuous ratings of perceived arousal and valence. The models explained up to 73% of the variation in arousal in terms of changes of loudness and tempo. The models for valence were less successful, only weakly associated with melodic contour, as well as loudness and tempo. Schubert suggested that the inconsistent predictions for valence were not surprising given that variables of mode and articulation, known to influence valence, could not be easily represented as interval-scale variables and were not included in the analysis. The lack of a clear relationship between perceived emotions and both texture and spectral centroid was likely a consequence of the stepwise regression modeling procedure, which would not include variables that are collinear and do not increase the predictive power. Additionally, it would be impossible to compare across musical contexts.

Research has shown that timbral attributes vary as a function of dynamics and pitch. For example, brightness perception depends on pitch, since increasing fundamental frequency also increases the spectral centroid (Schubert and Wolfe 2006). McAdams (2013) states that "sounds produced with greater playing effort (e.g., fortissimo vs. pianissimo) not only have greater energy at the frequencies present in the softer sound, but the spectrum spreads toward higher frequencies, creating a higher spectral centroid, a greater spectral spread, and a lower spectral slope" (45). A study design that specifically controls for other musical features, such as musical context and performance parameters, would assist in understanding the connection of brightness with emotional experiences.

Hypothesis

Taking the empirical evidence and associations in treatises into consideration, one could visualize the findings on the two-dimensional affect space. As shown in Figure 5-1 (left panel), the dimensional model represents arousal along the vertical dimension (low and high energy) and valence along the horizontal dimension (positive and negative affect). The research suggests that bright timbres (shown in yellow) are associated with high arousal emotions such as joy and happiness with positive valence (top right quadrant) and emotions such as anger and fear with negative valence (top left quadrant).[3] Dark timbres (shown in grey) are associated with low arousal emotions such as serenity and tenderness with positive valence (bottom right quadrant) and emotions such as sadness and sorrow with negative valence (bottom left quadrant). The effect of increasing brightness or darkness while keeping all other musical parameters constant is unknown. As shown in Figure 5-1 (right panel), we hypothesize that brighter versions would augment the response to the extremes along the valence dimension for high arousal emotions, as shown with the yellow arrows. Similarly, darker versions would augment the response to the extremes along the valence dimension for low arousal emotions (grey arrows in the figure).

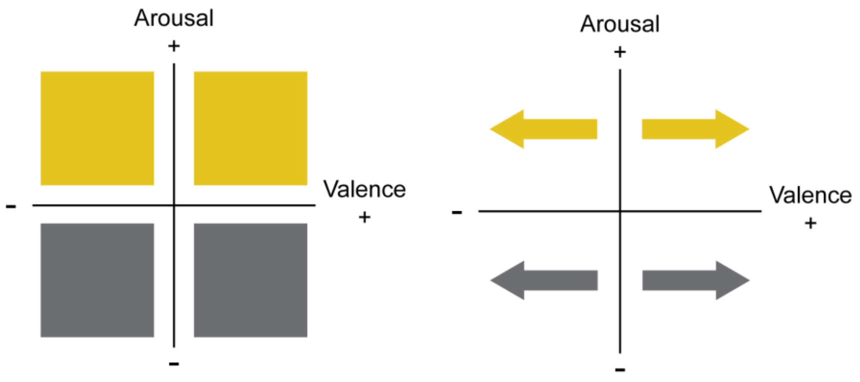

Figure 5-1. Left panel: Brightness and darkness associations mapped onto the 2-dimensional arousal and valence space; Right panel: Direction of predictions for augmenting the brightness and darkness.

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[3] Note, the research does not provide a clear understanding of the timbral properties that would distinguish between positive and negative valence for a given arousal level. We expect that the valence of the instrument timbre is interpreted differently depending on the musical context. This research question is out of the scope of the current study.

PRESENT RESEARCH

The aim of the work presented here was to investigate the effects of independently modifying spectral centroid through adjustments of instrumentation on felt emotional responses. Three excerpts were chosen that featured dramatic orchestral gestures, which had been found in a previous study to elicit strong emotional responses.[4] Expert reorchestrations were created to produce four new versions: brightened, darkened, and two hybrid combinations (dark-to-bright and bright-to-dark). We created realistic acoustical renderings of the original and reorchestrated versions, in which the performance timings and dynamic variations, based on real recordings, remained constant across versions.

A large-scale listening study used a converging-methods approach of both subjective and objective measures: self-reporting (concurrent and retrospective) and physiological measurement, respectively. In a group-listening experiment, we collected continuous ratings of felt arousal and valence and psychophysiological responses. As a measure of physiological arousal, changes in heart rate, respiration rate, and skin conductance have been found in relation to arousing music (Hodges 2010). Cacioppo, Bush, and Tassinary (1992) found evidence that facial muscle activity, even when too subtle to produce a perceptive expression, is modulated by affective and communicative processes. Activity of the *zygomaticus major* muscle occurs when the cheek muscles are tightened during smiling, whereas the *corrugator supercilii* muscle is responsible for lowering and contraction of the eyebrows during frowning or scowling (Tassinary, Cacioppo, and Vanman 2007). The zygomaticus and corrugator have been found to be active during music with positive and negative affect, respectively (Hodges 2010).

We investigated whether the emotional valence varied across the different orchestral versions. Given that the tempo and dynamics remain constant, we predict that the arousal ratings,

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[4] (Goodchild, Wild, and McAdams 2016) [Chapter 3].

skin conductance, respiration rate, and heart rate would be comparable across versions, but the valence ratings and affective facial musical tension would vary based on the brightness of the version. The arousal dimension, however, would temper the direction of the influence of brightness on the valence dimension. Figure 5-1 (right panel) above illustrates this hypothesized relationship between the orchestral version and felt emotion within the two-dimensional arousal and valence emotion space.

We created hybrid versions of the excerpts in order to investigate whether responses to the same instrumental scoring would vary based on differing preceding contexts. We tested the influence of the initial dark scoring on the second half of the dark-bright version compared to the fully bright version. Similarly, we tested the influence of the initial bright scoring on the second half of the bright-dark version compared to the fully dark version. We predicted that the preceding context would influence the responses, particularly at the moment of sudden textural change for the sudden addition and sudden reduction gestures given the strong emotional intensity ratings at these moments in the previous experiment.[5]

METHODS

Participants

One-hundred and eight participants (53 musicians and 55 nonmusicians, 52 males and 56 females) were recruited from the Montreal area via McGill University email lists and classified advertisements. The musician listeners (20 females) had an average age of 26 years (range 19-46) and had studied a minimum of 2 years in an undergraduate degree in music. The nonmusician listeners (36 females) had an average age of 27 years (range 18-59) and had less than two years of musical training in early childhood. Although outside the scope of this paper, musician and nonmusician

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[5] (Goodchild, Wild, and McAdams 2016) [Chapter 3].

listeners were included in order to assess the role of musical expertise on listening experience in future.

All participants were prescreened to ensure that they had normal hearing and no history of emotional disorders. On the day of the experiment, they agreed to avoid consuming high calorie foods and abstain from drugs and alcohol. They were asked to refrain from drinking caffeinated beverages four hours before the experimental session. They were required to fulfil at least one of the following criteria: enjoy listening to orchestral music (from the 19th and 20th centuries), experience emotional responses when listening to music, and/or experience physical responses to music (chills, tears, etc.). Men were asked to be clean shaven, and women were asked to avoid wearing foundation makeup on the forehead and cheeks.

Apparatus

Physiological measurements were recorded through six ProComp Infiniti units (Thought Technology Ltd., Montreal, Canada) that were adhered to the bottom of participants' seats. Each ProComp Inifinti unit was connected via a USB hub to an Apple Mac Pro computer (Apple Inc., Cupertino, CA). A custom program received, decoded, and stored all data packets on an internal hard disk.

Respiration rate was measured using a belt attached around the chest just below the pectoral muscles that recorded volume changes of the chest with a stretch sensor (Resp-Flex/Pro, SA9311M). Blood volume pulse (BVP) was measured using a photoplethysmograph (BVP-Flex/Pro SA9308M) on the palmar side of the distal phalange of the middle finger on the nondominant hand. Skin conductance (SC) was measured using sensors (SC-Flex/Pro, SA9309M) on the distal phalange of the index and ring fingers of the non-dominant hand. Expressive facial muscle activations were measured using two surface electromyography (EMG) sensors (MyoScan-Pro T9401M-60) placed on the *corrugator supercilii* muscle (associated with frowning) and *zygomaticus major* muscle (associated with smiling). EMG sensors were placed on the right side of the face with positive and negative electrodes aligned with the respective muscles and reference electrodes placed on the cheek bone/forehead.

Participants were provided with an iPod Touch (Apple Inc., Cupertino, CA), which was attached on the thigh of the dominant leg with a Velcro strap. The iPod data were sent wirelessly from the devices to the Mac Pro computer.

Stimuli

The fifteen stimuli used in the experiment were based on three excerpts, listed in Table 5-1. Each excerpt was expertly reorchestrated by composers John Rea, Denys Bouliane, and Félix Frédéric Baril to modify the spectral centroid through adjustments in instrumentation.[6] Four new versions were created: brightened (globally increased spectral centroid), darkened (globally decreased spectral centroid), and two hybrid combinations (dark-to-bright and bright-to-dark). The hybrid versions were created by combining sections of the bright and dark versions. For the sudden category excerpts, the sections were divided at the point of the sudden textural changes. For the gradual excerpt, the recombination occurred progressively starting at one extreme, moving through the original version, and ending at the other extreme.

Given the novel nature of this reorchestration task, several constraints were enforced.[7] First, the new version must be playable by a real orchestra. Second, the style and character of the original version should be preserved. Finally, the overall pitch range and textural density should be comparable, with the aim of only shifting the spectral weight. The reorchestration strategies include

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[6] Details regarding the reorchestrations are outlined in the companion paper (Goodchild 2016b) [Chapter 4].

[7] The reorchestration strategies and constraints are discussed in detail in the companion paper (Goodchild 2016b) [Chapter 4].

transferring or doubling parts within and outside the instrumental family, doubling or shifting parts by an octave, and changing the playing techniques (e.g., bowing, mutes, and harmonics). Overall, the composers' adjustments focus on the colouring, balance and weight of the instrumental parts, targeting certain frequency ranges.

Table 5-1. List of musical excerpts

Type	Composer	Piece	mm.	Recording	Assigned
Gradual Addition	Claude Debussy	*La Mer*, I (1905)	122-141	Berliner Philharmoniker, conducted by Sir Simon Rattle, EMI Classics, 2005	Bouliane
Sudden Addition	Ralph Vaughan Williams	*London Symphony*, I (1914)	8-53	Royal Liverpool Philharmonic Orchestra, conducted by Vernon Handley, EMI Classics, 2011	Baril
Sudden Reduction	Gustav Holst	*The Planets*, "Uranus" (1916)	193-236	London Philharmonic, conducted by Sir Adrian Boult, EMI Classics, 2002	Rea

We created realistic acoustical renderings of the original and the four reorchestrated versions using the Digital Orchestra Simulator (DOSim), an orchestral rendering environment currently being developed by Bouliane and Baril (2014). DOSim uses Finale (Make Music, Inc., Boulder, CO) for music notation, Kontakt 5 (Native Instruments, GMbH, Berlin, Germany) as the sampling engine, Logic Pro (Apple Inc., Cupertino, CA) for stereo mixing, and various recorded sound samples from the Symphonic Cube (Vienna Symphonic Library GmbH, Vienna, Austria), and Xsample Library (Hans Josef Winkler, Detmold, Germany). The system allows for precise control of real instrumental samples and various performance parameters, such as gradients in dynamics, attack speed, vibrato rate and control, bowing speed and timing, and balance within and across instrumental families. Kontakt 5 was used to add hall reverberation and background noise. Logic was used to record the direct audio to a high quality WAV file. The performance interpretations of the beat-to-beat tempo variations and global sound levels, based on commercial recordings (see Table 5-1), were held constant across versions. To listen to these reorchestrations, consult the supplemental material.[8]

The stimuli were stored on a Mac Pro computer (Apple, Inc., Cupertino, CA), amplified through a Grace Design m904 monitor (Grace Design, Boulder, CO), and were played over Dynaudio BM6a loudspeakers (Dynaudio International GmbH, Rosengarten, Germany). The stimuli were presented at a comfortable listening level that was kept constant for all sessions. In separate pilot tests, the level of each excerpt was set to match a concert experience, such that the excerpts corresponded to the relative dynamic level of the scores and were not too loud or soft. Sound levels for each excerpt were measured with a sound-level meter (Brüel & Kjær Type 2205, A-weighting) placed at the level of the listener's ears in the front and rear rows, with maximum values ranging between 85.4 and 91.5 dB (mean = 87.9, SD = 2.13).

Procedure

The experiment took place at the Music Perception and Cognition Lab at the Schulich School of Music of McGill University. Twenty group-listening sessions were held to represent a concert experience. In each session, a maximum of six participants listened in a dimmed room with acoustic absorbing material on the walls at a comfortable temperature (22°C). Each session was video recorded.

On arrival participants were randomly assigned to a seat, staggered within three rows of four chairs facing two loudspeakers arranged at ±45° (see Figure 5-2 for seating arrangement). An empty chair between participants reduced distraction and allowed the placement of the clipboard when not in use. Participants were first asked to sign an informed-consent form and read the instructions on a clipboard. The fingers, forehead, and cheek of each participant were cleaned with an alcohol swab.

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[8] http://sites.music.mcgill.ca/orchestration/projects/dosim-reorchestration/

The biosensors were attached and the iPod was secured to the leg. After verbal instructions were given to the group, the signals of the iPod and physiological sensors were verified.

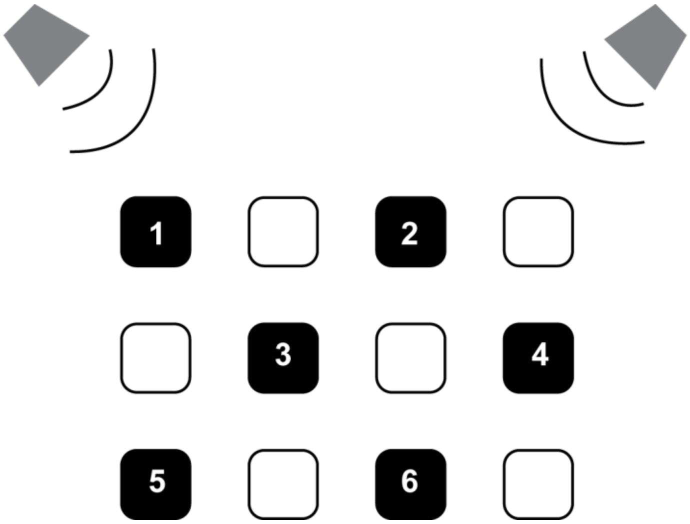

Figure 5-2. Seating arrangement for experiment. Black squares indicate chairs used. White squares indicate empty chairs. Grey quadrangles represent speaker placement and orientation.

The first part of the experiment consisted of a practice trial, which allowed participants to ask questions and familiarize themselves with the experimental procedure. All participants in each session heard the same practice piece as a common anchor for rating. The practice piece was an excerpt from Antonín Dvořák's Symphony 9, I (mm. 200-286) used in a prior study.[9] Participants were told that the practice piece was representative of the music they would hear in the main experiment. The data from the practice stage were not analyzed.

The main experiment consisted of three stimuli, each preceded by minute-long periods in which baseline measurements from the biosensors were recorded. During the baseline periods, the

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[9] (Goodchild, Wild, and McAdams 2016) [Chapter 3]

participants were asked to relax, breathe normally, and refrain from moving. Table 5-2 lists the stimuli played in the three time slots of each session. Each participant heard only one instance of each excerpt and did not hear an orchestral version more than once (e.g., one group would not hear two bright versions). The stimulus presentations were counterbalanced such that each stimulus was played the same number of times over the 20 sessions, and each version occurred uniformly in each time slot.[10] The participants were recruited to ensure that each session had a nearly equal number of musicians and nonmusicians, as well as males and females. The resulting number of participants for each stimulus ranged between 20 and 24 participants (mean = 21, SD = 1). The experimental session lasted approximately 45 minutes and the participants were paid $10 for their participation.

Table 5-2. Stimuli played in each session. Legend: O = original, BB = bright, DD = dark, BD = bright-dark, DB = dark-bright; 1 = Debussy, 2 = Vaughan Williams, 3 = Holst

Session	Slot 1		Slot 2		Slot 3	
	Version	Excerpt	Version	Excerpt	Version	Excerpt
1	O	1	DD	2	BB	3
2	DB	1	O	2	DD	3
3	DD	1	BD	2	O	3
4	O	2	BB	1	DB	3
5	BB	2	O	3	BD	1
6	BD	2	DB	3	O	1
7	DD	3	DB	2	BB	1
8	BB	3	DD	2	BD	1
9	DB	2	BD	3	DD	1
10	BD	3	BB	2	BD	1
11	BB	1	O	2	DD	3
12	DD	1	DB	2	O	3
13	O	1	DD	2	BD	3
14	DB	1	O	3	BB	2
15	BD	2	BB	3	O	1
16	O	2	BD	3	DB	1
17	BB	2	DD	1	DB	3
18	BD	2	BB	1	DD	3
19	DD	2	DB	3	BD	1
20	DB	2	BD	1	BB	3

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[10] We wish to thank Professor Rhonda Amsel at McGill University's Psychology department for her assistance with the design.

Continuous ratings of arousal and valence

While listening to each excerpt, participants continuously rated felt arousal and valence on the iPod Touch screen using the index finger of their dominant hand. Figure 5-3 shows the two-dimensional emotion space.[11] The x-axis represents the valence dimension, with positive emotions on the right and negative emotions on the left. The y-axis represents the arousal dimension, high energy emotions at the top and calm emotions at the bottom. Text in white was shown on the iPod screen, whereas text in black was provided in the instructions as examples of where common emotions would be positioned within the space. The extremes of the rating scales (outer edge of the screen) represented the most intense emotional response they had experienced listening to music. This anchoring was chosen to ensure that participants used the majority of the range of the two-dimensional emotion space while preventing them from overuse of the maximum end, thereby creating a flat line of the signal and data loss. Participants were asked to begin each excerpt with their finger in the center of the screen in the black crosshairs (neutral) and keep their finger on the screen while listening.

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[11] The iPod Touch interface was designed and implemented by Egermann et al. (2013).

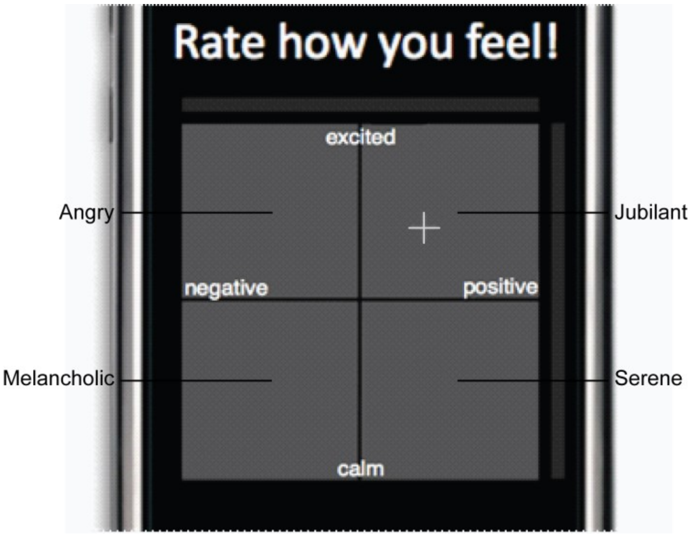

Figure 5-3. iPod Touch interface with two-dimensional valence (x-axis) and arousal (y-axis) dimensions. Text in white was visible to participants. Text in black represents examples of emotions found in each quadrant that were provided in the instructions. Grey cross indicates finger placement.

Questionnaires

Before and after the experimental session, participants completed the International Positive and Negative Affect Schedule Short Form (I-PANAS-SF), with the five positive affects (alert, inspired, determined, attentive, and active) and five negative affects (upset, hostile, ashamed, nervous, and afraid) (Thompson 2007). The responses were changed from a general question of mood ("Thinking about yourself and how you normally feel, to what extent do you generally feel…") to a question of their current mood-state ("To what extent do you currently feel…"). The interval measure on a 5-point Likert scale was adjusted from "never — always" to "very low — very strong."

After each excerpt, participants completed retrospective questionnaires on the iPod Touch screen. Participants rated their familiarity ("Did you know this excerpt?") and their preference ("Did you like this excerpt?") on seven-point scales. They were also asked about specific physical reactions, such as the number of experienced chills.[12]

After the main experiment concluded, participants completed a final questionnaire outlining their musical training, listening habits and preferences, socio-demographic characteristics, personality, and their experience using the iPod Touch and wearing the biosensors.

Data analysis

Behavioural and physiological data

The behavioural and physiological data of all continuous signals were preprocessed in MATLAB (Mathworks, Version R2010a). One participant failed to use the iPod device and ignored requests to stop fidgeting with the fingers that were wired with sensors throughout the session; therefore, his/her data were removed for all excerpts. Visual inspection of the physiology signals and video recordings of the sessions revealed a few instances of technical malfunctions and signal loss, which lead to the removal of these data for the excerpt. No more than two participants' data were lost for any biosignal measure for a particular stimulus.

For activity analysis, the behavioural and psychophysiological data were preprocessed (filtered and normalized) depending on signal type and all were resampled at 128 Hz.[13] The behavioural data and skin conductance were range-normalized for each participant across the three excerpts and a phaseless, low-pass ($f_c = 0.1$ Hz) 4th-order Butterworth filter was applied. The EMG signals were band-pass filtered between 15-30 Hz, rectified by obtaining the absolute values and

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[12] The questionnaire also included questions about several other subjective experiences, but will not be reported here due to the scope of the paper. Participants were asked if they experienced physical reactions including tears, sense of awe, and action tendencies (i.e., urges to move to the music). In addition, a randomized order of emotional models was used, which included the Geneva Emotional Scale (GEMS-9) (Zentner, Grandjean, and Scherer 2008), the 3-dimensional model (Schimmack and Grob 2000), and the basic emotion model (Ekman 1999). Participants were instructed to rate the intensity of their emotional responses to the excerpt for each emotion term, rated on a seven-point scale from 1 representing "not at all" to 7 representing "extremely."

[13] We thank Finn Upham for her assistance in preprocessing the signals to be used for activity analysis.

normalized for each participant.[14] The respiration rates and heart rates were extracted using filterbanks of sinusoids on downsampled first-order differenced series of the filtered signals.[15] The time series were then filtered with a phaseless, low-pass (f_c = 0.1 Hz) 4th-order Butterworth filter and upsampled back to 128 Hz.

Visualizations

Spectral centroid was extracted from the DOSim-rendered excerpts with PsySound3 (Cabrera, Ferguson, and Schubert 2007). The spectral centroid was extracted in Hz (frequency). Each time series was resampled at 2 Hz and smoothed with a phaseless, low-pass (f_c = 0.2 Hz) 4th-order Butterworth digital filter. The first two seconds were cut due to the issue at the beginning of recordings with only a few instruments playing, which created a spurious high spectral centroid from the background noise of the DOSim renderings.

The behavioural data were resampled at 2 Hz, normalized, and filtered with a phaseless, low-pass (f_c = 0.2 Hz) 4th-order Butterworth filter with a cut-off frequency of 0.2 Hz.[16] The data were scaled between 0 and 1 based on the minimum and maximum of each participant across the three stimuli they heard in the session. This normalization reduces the inter-participant variability due to different ranges of rating.

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[14] The resulting signals resembled a Poisson distribution, in which the data are bounded on one end, in comparison to a bell-shaped Gaussian distribution. Given that the variance of the Poisson distribution is equal to its mean, the responses were normalized by dividing the respective participant's average over all of their fully-rectified signals for that sensor.

[15] The respiration filterbank contains sinusoids reflecting 1, 5-30 breaths per minute (to capture slow and faster breathing rates) in increments of 0.25 breaths per minute. The heart rate filterbank contains sinusoids of 50-120 beats per minute in increments of 0.5 beats per minute. The original signals were downsampled to 8 Hz and segmented into overlapping time windows of 100 ms. The procedure calculates the highest correlation between each window of the signal and the sinusoids in the filterbank. This results in an array with respiration or heart rates for each time window, which is then interpolated to provide a continuous signal. This method is based Müller (2007).

[16] The data were resampled using MATLAB's interpolation function "interp1" with the nearest neighbour method.

RESULTS

Retrospective ratings

Mood-state questionnaire

Statistical tests on retrospective ratings were conducted with SPSS Statistics (IBM, Armonk, NY). A nonparametric Wilcoxon signed-rank test was used to determine if there were any significant differences in the responses to the I-PANAS-SF mood questionnaire before and after the experiment. The values for each category of positive and negative affect were summed for each participant. No statistically significant median differences were found at the end of the experiment compared to the beginning for both positive [$Z = -.95$, $p = .34$, $r = -.09$] and negative [$Z = -1.87$, $p = .06$, $r = -.18$] affect ratings.[17] This result indicates that participants' moods were not significantly affected by the experimental procedure.

Apparatus questions

Participants were asked about the ease of use of the two-dimensional emotion space on the iPod interface on a seven-point scale (1 = very difficult, 7 = very easy). The ratings were very high overall, with a median of 7.0 (range = 6.0).[18] For the question regarding the impact of using the iPod on the listening experience (1 = distracting, 7 = improved focus), the ratings were moderate (neutral), with a median of 4.0 (range = 6.0). Finally, participants were asked about the biosensors' impact on the listening experience (1 = distracting, 7 = improved focus), and there was a median of 4.0 (range = 6.0). The results indicate that the use of the iPod and biosensors generally did not distract or impede on the listening experience too strongly.

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[17] For positive affect ratings, 45 participants had positive differences (rated positive affects more strongly), 50 participants had negative differences (rated positive affects less strongly), and 12 people did not change. For negative affect ratings, 21 participants had positive differences (rated negative affect more strongly), 51 had negative differences (rated negative affect less strongly) and 35 did not change.

[18] The median, range and interquartile range (used below) are included because they involve fewer assumptions about the data distribution and are less susceptible to outliers compared to the mean and standard deviation.The range is calculated by subtracting the minimum rating from the maximum rating.

Familiarity

The familiarity scores as recorded on a seven-point scale were low overall, with a median across excerpts of 1 (range = 6). Table 5-3 reports the median ratings, range, and the results of the nonparametric Kruskall-Wallis H test, which compared ratings of familiarity across the five experimental conditions for each excerpt. Significant differences were found for the Debussy and Vaughan Williams excerpts. Pairwise comparisons were performed using Dunn's (1964) procedure with a Bonferroni correction for multiple comparisons with adjusted p-values. For the Debussy excerpt, no significant differences among the versions were found. For the Vaughan Williams excerpt, the post hoc analysis revealed significant differences in ratings between the dark (*n* = 22, *Mdn* = 1, mean rank = 40.8) and bright (*n* = 22, *Mdn* = 1, mean rank = 60.25) versions, *p* = .024, but not between any other versions.

Table 5-3. Median and range of familiarity ratings, Kruskall-Wallis H statistic (versions), significance level (* *p* < .05)

	Debussy	Vaughan Williams	Holst
Median	1	1	1
Range	6	4	6
Kruskall-Wallis *H*	9.68	11.6	2.99
p	.05*	.02*	.56

Preference

The preference scores as recorded on a seven-point scale were moderate overall, with a median across excerpts of 4 (range = 6). Table 5-4 reports the median ratings, range, and the results of the Kruskall-Wallis H test, which compared ratings of preference across the five experimental conditions for each excerpt. Significant differences were found for the Vaughan Williams excerpt. Pairwise comparisons were performed using Dunn's (1964) procedure with a Bonferroni correction for multiple comparisons with adjusted p-values. The post hoc analysis revealed significant differences in ratings between the dark-bright (*n* = 23, *Mdn* = 2, mean rank = 38.4) and bright (*n* = 22, *Mdn* = 4, mean rank = 67.1) versions, *p* = .017, but not between any other versions.

Table 5-4. Median and range of preference ratings, Kruskall-Wallis H statistic (versions), significance level (* *p* < .05)

	Debussy	Vaughan Williams	Holst
Median	4	3	3
Range	6	6	6
Kruskall-Wallis *H*	2.89	10.9	7.46
p	.58	.03*	.13

Chills

Participants reported between 0 and 11 chills experienced during the entire experiment, with a median across excerpts of 0 (range = 11). Figure 5-4 is a histogram of the number of chills reported. Sixty-eight participants (63.0%) did not experience any chills.

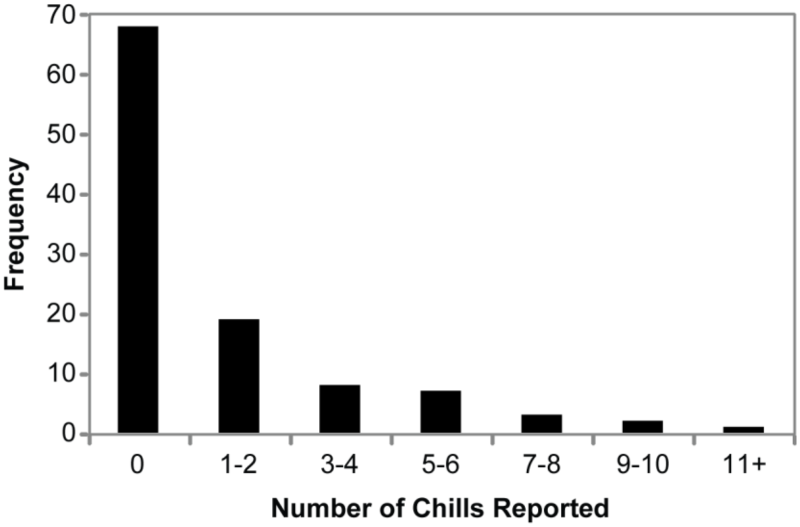

Figure 5-4. Histogram of the number of chills reported during the experiment

Table 5-5 reports the median number of chills, range, and the results of the Kruskall-Wallis H test, which compared ratings of preference across the five experimental conditions for each excerpt. No significant differences in the number of reported chills across the five experimental conditions for each excerpt at $p < .05$.

Table 5-5. Median and range for the number of reported chills, Kruskall-Wallis H statistic (versions), significance level (* $p < .05$)

	Debussy	Vaughan Williams	Holst
Median	0	0	0
Range	5	3	5
Kruskall-Wallis *H*	2.03	3.06	4.41
p	.73	.55	.35

Visualizations

Spectral centroid comparison

Based on aural examination and consultation of the time-varying spectral centroid, the composers were successful in making adjustments to change the timbral brightness globally. Figure 5-5 compares the spectral centroid time series of the original and reorchestrated versions rendered by DOSim. Vertical lines indicate the moment of sudden change for the sudden addition of the Vaughan Williams excerpt and the sudden reduction of the Holst excerpt, as well as the large sectional divisions for the gradual addition of the Debussy excerpt.

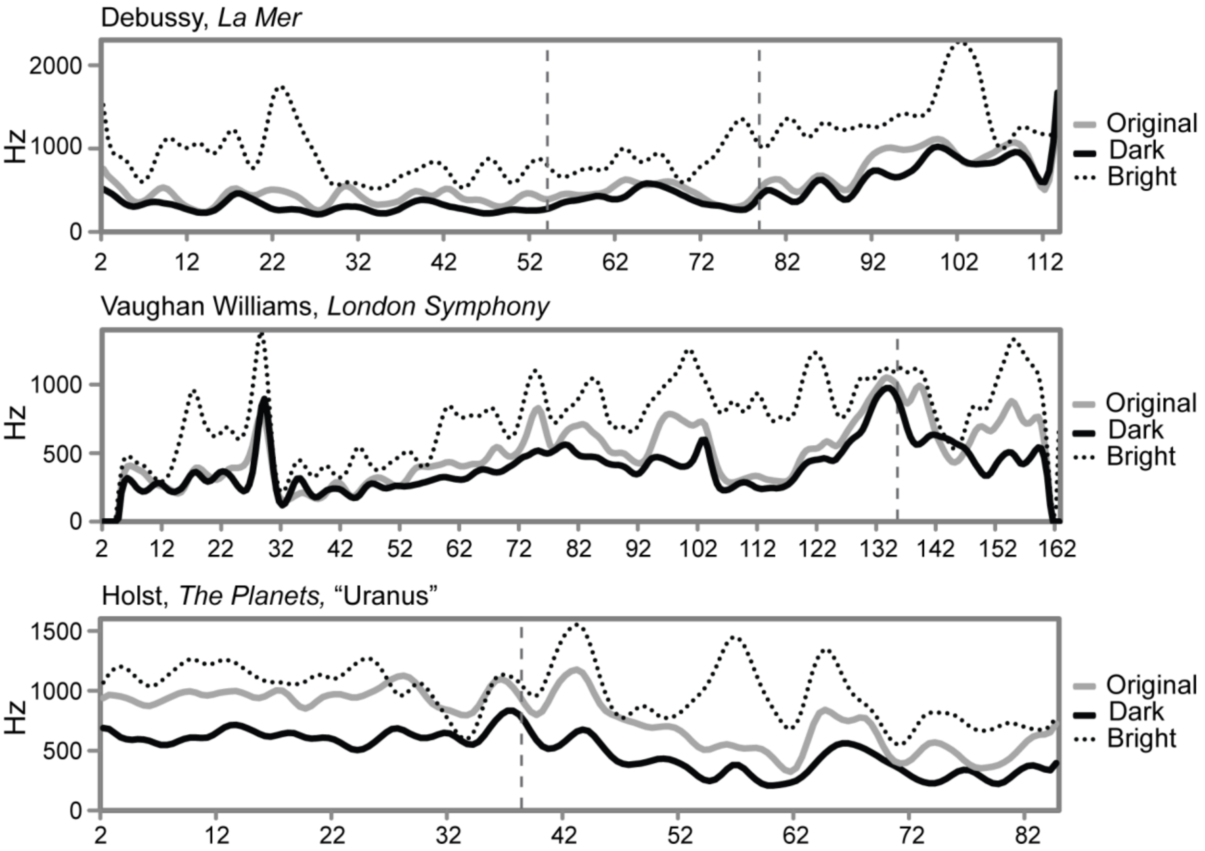

Figure 5-5. Spectral centroid comparison of the original, dark and bright versions of the three excerpts: Debussy, *La Mer* (gradual addition), Vaughan Williams, *London Symphony* (sudden addition), Holst, *The Planets,* "Uranus" (sudden reduction). Vertical lines indicate structural segments.

Arousal and valence ratings

As a measure of central tendency, the average arousal and valence ratings were graphed over time for the original, dark, and bright versions of the Debussy, Vaughan Williams, and Holst excerpts (see Figure 5-6).[19] The shaded clouds around the mean curves represent ±1 standard deviation. Dotted, vertical lines indicate the sudden textural changes of the Vaughan Williams and the Holst excerpts and the three main sections of the Debussy excerpt. Given the high variability for both arousal and valence measures, we cannot assume response coordination or that there are any statistically significant differences across versions. The average ratings provide a sense of the general

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[19] We developed these graphs using the "shadedErrorBar" function from MATLAB (Campbell 2010).

trends and instances where the tendencies across versions are similar or where they diverge, the analysis of which must be interpreted with caution given the inter-subject variability.

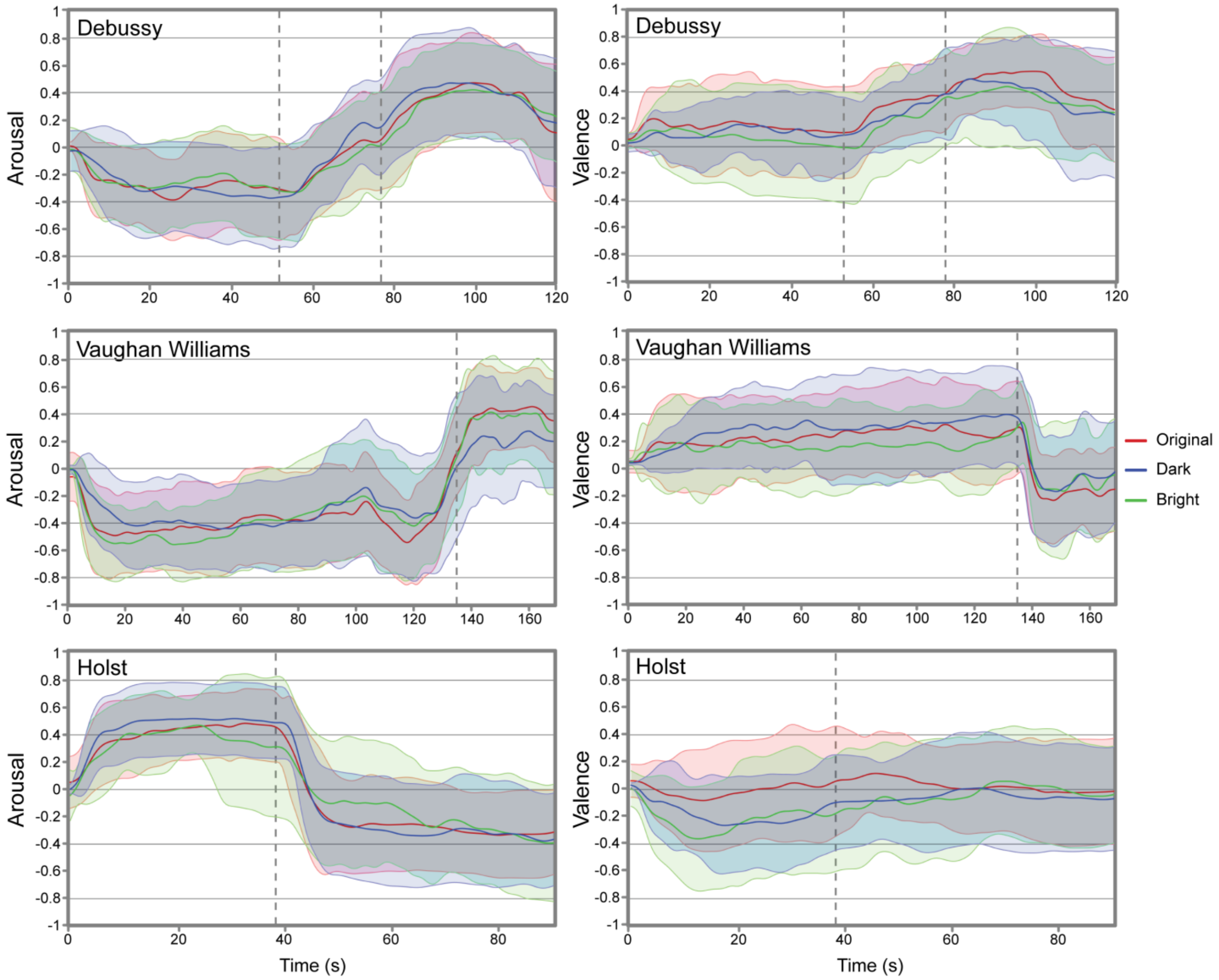

Figure 5-6. Mean arousal and valence ratings for the original (red line), dark (blue line), and bright (green line) versions of the Debussy, Vaughan Williams, and Holst excerpts. Light red, light blue, and light green shaded regions indicate ±1 standard deviation from the average of the original, dark, and bright versions, respectively. Overlapping areas are represented by shading in various colour combinations. Vertical dotted lines represent sectional divisions.

Generally, the arousal ratings across versions correspond quite closely to one another. The valence dimension appears to be less dynamic compared to the arousal dimension. The one exception is the Vaughan Williams excerpt, in which the valence ratings turn abruptly negative after the sudden addition, while the arousal ratings increase rapidly in anticipation for and in response to this sudden textural change. For the Debussy and Holst excerpts, the original version is rated consistently highest in valence, going against the original hypotheses. Before the sudden addition, the valence ratings of the Vaughan Williams excerpt appear to follow our predictions that the darker version would augment the response along the valence dimension and the brighter version would move in the opposite direction (given the low arousal and positive valence for the original version). Overall, the bright version seems to be consistently rated more negatively compared to the original and dark versions. Since these observations are limited in the lack of statistical precision, we turned to activity analysis to investigate response coordination for arousal and valence ratings, as well as the physiological measures.

Activity analysis

Introduction

Given that we listen to music in time, the ability to measure continuous responses allows researchers to explore moment-to-moment changes in listeners' experiences. Traditionally, the responses of a group of listeners are averaged as a measure of central tendency (Krumhansl 1997; Nielsen 1983; Schubert 2004). However, researchers often ignore the problematic nature of interpreting mean or median ratings related to the response variability across participants. For time series data, the variance at each sample point may not be normally distributed and the variance may change over time. As a result, one cannot differentiate between instances where there is coordination among participants and instances of disagreement.

Activity analysis, currently being developed by Upham and McAdams (2014), is an analytical approach that focuses on particular active types of events in continuous responses (e.g., increases in arousal ratings above a certain threshold), considers the coincidence of a given activity over multiple responses to the same stimulus, and statistically evaluates response coordination. The researcher defines the type of response event, determines whether the timing of the event is consistent across participants, and then investigates which aspects of the stimulus elicit this response.

Figure 5-7 presents an example of an activity-level time series. For each window of synchrony—an interval of time in which response events are counted as occurring simultaneously—the activity level measures the proportion of responses that feature the same kind of event above a certain threshold. In this case, the figure shows the proportion of arousal ratings (between 0 and 100%) that increased (red, above) and decreased (blue, below) for non-overlapping windows of 1 second with a minimum change threshold of 2% of the rating scale.[20] Similar activity occurred across versions, with many decreases for the first 10 seconds and low activity during the middle section. Directly before and after the sudden addition (shown with the vertical dotted line), approximately 50% of the participants had increasing arousal ratings.

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[20] Activity-level parameters and thresholds will be discussed further below. These values were chosen in consultation with Finn Upham through personal communication (July 2014).

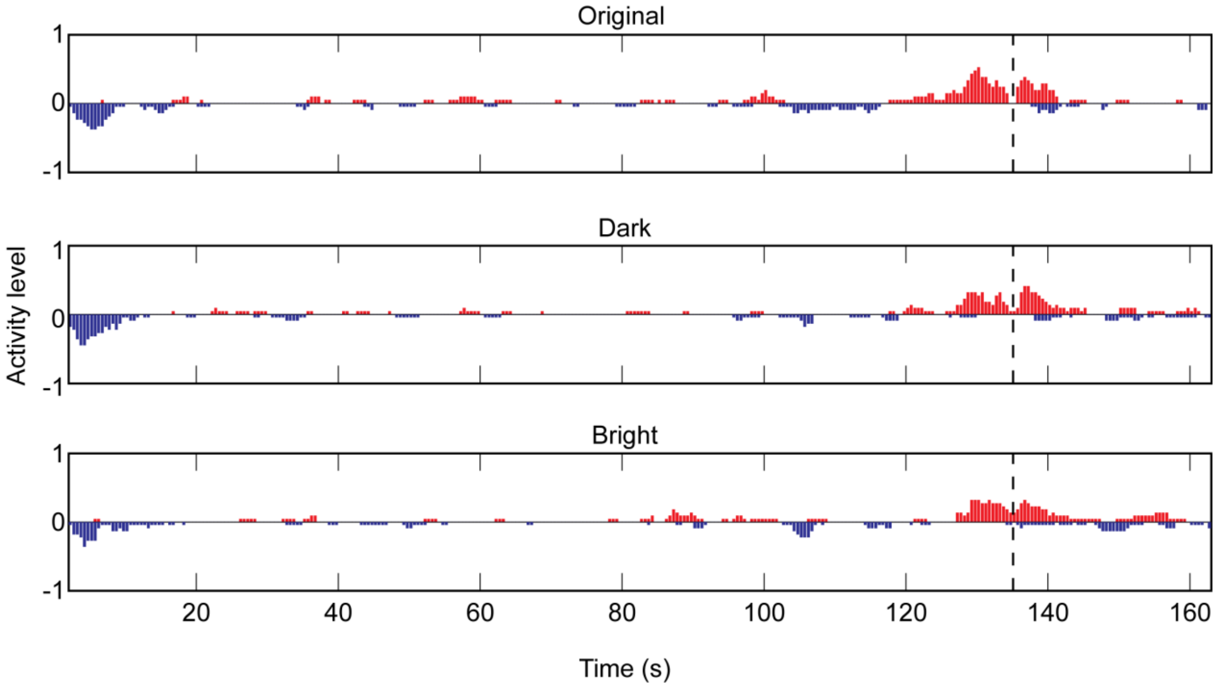

Figure 5-7. Activity-level time series for increasing and decreasing arousal responses for the original, bright, and dark versions of the Vaughan Williams excerpt.

High activity within a specific time frame does not, in and of itself, indicate that the responses are driven by the stimulus. A coordination test evaluates the likelihood that the response activity is statistically different from random processes. Note that a collection of uncoordinated responses would have a Poisson-like activity level distribution with low-to-mid activity across all time frames, whereas a coordinated collection would have synchronized moments of high-activity levels and low-activity levels. A test against the null hypothesis of independently timed changes in activity compares the activity-level distribution for a collection of uncoordinated responses to the actual experimental data. Since our data include types of responses that are quasi-regular, such as heart rate and respiration rate, we opted for a non-parametric approach, which uses the experimental response data to generate the distribution of alternatives. By shuffling the entire series of each participant's response by a uniform interval, the alignment among responses is broken and new alternative activity-level time series are generated.[21] This process is repeated thousands of times to produce distributions of activity levels at each time frame. If the experimental alignment is more extreme than 95% of the generated alternative alignments, the activity of the experimental data is considered to be significantly different from random processes at $p < .05$. A *p*-value is calculated from the rank of the experimental distribution's Euclidian distance from the alternative distributions.

Once a collection has been identified as showing significant coordination compared to random responses, Upham and McAdams investigate which individual events have higher or lower activity than would be expected randomly. These "significant moments of local activity" are calculated by comparing the experimental data to the median of the alternative activity levels. Returning to the Vaughan Williams excerpt described above, the pink highlighted regions in Figure 5-8 indicate the significant moments of increasing arousal ratings above a threshold of 2% of the rating scale with a window of synchrony of 1 second in relation to the median of 2000 alternative activity level distributions for that same time interval, represented by the grey line. All three versions had significant moments of increasing arousal directly before and after the sudden addition in comparison to random activity. There are also several other bursts of significant activity depending on the version, particularly between 80 and 100 seconds in the bright version.

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[21] Upham and McAdams (2014) developed this method from Grün (2009).

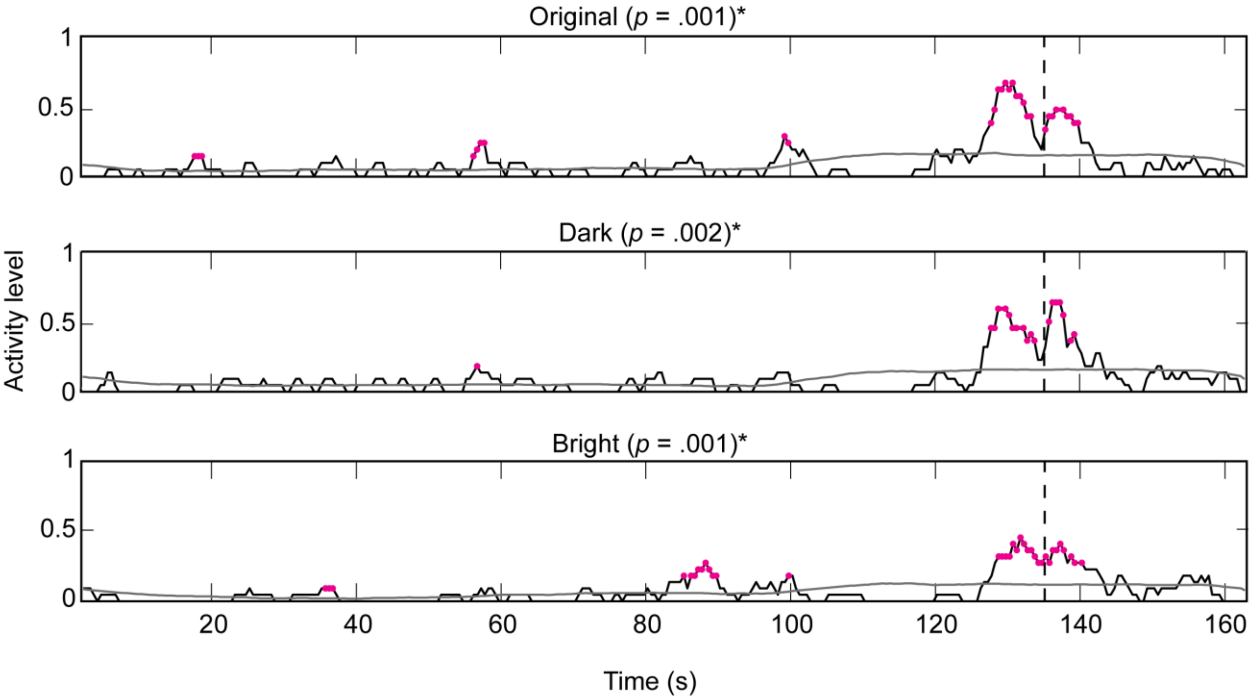

Figure 5-8. Increasing arousal activity (black) above a threshold of 2% for the original, bright, and dark versions of the Vaughan Williams excerpt. Pink highlighting indicates significant moments of local activity. The grey curve represents the median of the alternative activity levels. Asterisks indicate significance level of $p < .05$.

Present research

Activity analysis will be used to investigate whether there are differences in audience coordination and response activity across the original, bright, and dark versions of the three excerpts for all of the collected emotional response measures. Additionally, activity analysis will be used to examine whether there were context effects by comparing the hybrid versions to the fully dark and bright versions. Measures of arousal include heart rate (HR), respiration rate (RR), skin conductance (SC), and behavioural arousal ratings. Measures of valence include facial EMG of the zygomaticus (EMGz) and corrugator (EMGc), as well as behavioural valence ratings.

The activity analysis parameters and thresholds were carefully selected based on the type of activity of the signals, given that these values have not yet been evaluated empirically. Upham and McAdams recommend the smallest possible window of synchrony, which was a 2-second window for the full movements they analyzed (Upham and McAdams 2014). Due to the shorter excerpts in the current study, we decided on a 1-second window of synchrony, which was deemed to be a reasonable especially for self-reporting behavioural measures, given the response latency reported as 1-3 seconds after a stimulus event (Schubert 2012; Schubert 2010).

The non-parametric coordination test requires the selection of a shuffling window, a uniform time frame over which the responses are rearranged in order to produce alternative activity-level time series and activity-level distributions. Upham and McAdams note that the shuffling window should be chosen with consideration of the temporal structure of the activity. For periodic events (e.g., heart rate and respiration rate), the shuffling window should be larger than one period, but not large enough that the sensitivity is lost. Therefore, we chose a shuffling window of 60 seconds to preserve the general sense of evolution over time of activity, but also break up local alignment.[22]

Thresholds were chosen based on capturing the appropriate type of active events. We explored thresholds for each type of measure and tuned them to capture the type of relevant activity based on the ratio of local high activity to local low activity. If a threshold is too low, it will capture too many active events. If it is too high, it will not register any activity. For behavioural ratings, two types of activity were explored. The first type of activity captures increases (or decreases) of at least 2% or 3% of the rating space.[23] The second type captures activity crossing a certain maximum or minimum point of the scale: upper bound or lower bound, respectively. With the iPod range falling between 0 and 1, the upper bound was set to 0.6 or 0.7 and the lower bound was set to 0.3 or 0.2.

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[22] The window of synchrony and shuffling window were chosen based on personal communication with Upham (July 2014).

[23] This range of thresholds was recommended by Upham through personal communication (July 2014) and is similar to the threshold used in (Upham and McAdams 2014)

Upper and lower bounds were also set for the physiological measures.[24] For HR and RR, the upper and lower bounds, which would capture activity above and below a certain level, were set to +/- 1, 1.5 and 2. For SC and EMG, only the activity above a certain threshold was considered. The upper bound for SC was set to 0.5, 1, and 1.5. The EMGz and EMGc upper bound was set between 2.5 and 5 in increments of 0.5.

Tables 5-6, 5-7, and 5-8 report the results of the Debussy, Vaughan Williams, and Holst excerpts, respectively. Each table lists all of the collected emotional response measures for the original, dark, and bright versions and the *p*-values with at least one version coordinated ($p < .05$). Blank rows indicate that no version was coordinated for that type of measure. The threshold reported was chosen as the highest with at least one version coordinated.

Debussy excerpt

The Debussy excerpt features a gradual addition orchestral gesture that builds in intensity and orchestral forces over three stages. The arousal ratings were very similar across the versions. For increasing activity and activity above the upper bound, all three versions were coordinated. Only the bright version was not coordinated for decreases in arousal ratings. Considering the activity for increases/decreases and upper bound/lower bound, the arousal levels of the participants dropped initially, but began increasing during the second section, but did not reach their maximum arousal level until the third section.

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[24] This approach was recommended by Upham through personal communication (July 2014).

Table 5-6. Audience coordination of emotional response measures for various activity types and thresholds for the Debussy excerpt (original, dark, and bright versions). Asterisks indicate *p* < .05.

Measure	Activity	Threshold	Original	Dark	Bright
Arousal	Increases	2%	.001*	.001*	.001*
	Decreases	3%	.007*	.006*	0.09
	Upper bound	0.7	.001*	.001*	.001*
	Lower bound	0.3	.01*	.007*	.01*
RR	Upper bound				
	Lower bound				
HR	Upper bound	1.5	.007*	.01*	.01*
	Lower bound				
SC	Upper bound				
Valence	Increases	3%	.003*	.004*	.07
	Decreases				
	Upper bound	0.7	.001*	.001*	.05*
	Lower bound				
EMGz(+)	Upper bound	3.5	.002*	.007*	.29
EMGc(-)	Upper bound				

For the physiological measures that are typically associated with arousal level (SC, RR and HR), there was significant audience coordination for heart rate only. As shown in Figure 5-9, the majority of participants had significant moments of local activity (see green highlighting) below the average of the shuffled alternatives (an estimate of random activity) at the beginning of the excerpt. Extensive peaks in heart rate occurred during the transition into the second section (see pink highlighting). Rapid heart rate deceleration also occurred after the arrival point in the third section. Overall, the heart rate for most participants dipped at the beginning, peaked during the first and second sections and dropped after the climax in the third section. We suggest that the heart rate varied in relation to the structure of the excerpt, reflecting orienting responses. Bradley and Lang (2007) explain this phenomenon as the first stage of defensive activation involving heightened attention before an overt fight-or-flight responsive reflex. This orienting response is signaled by cardiac deceleration and slight skin conductance increases. Lundqvist et al. (2009) also reported heart rate deceleration and acceleration patterns at the beginning of each musical stimulus, which they suggested reflected shifts in attention.

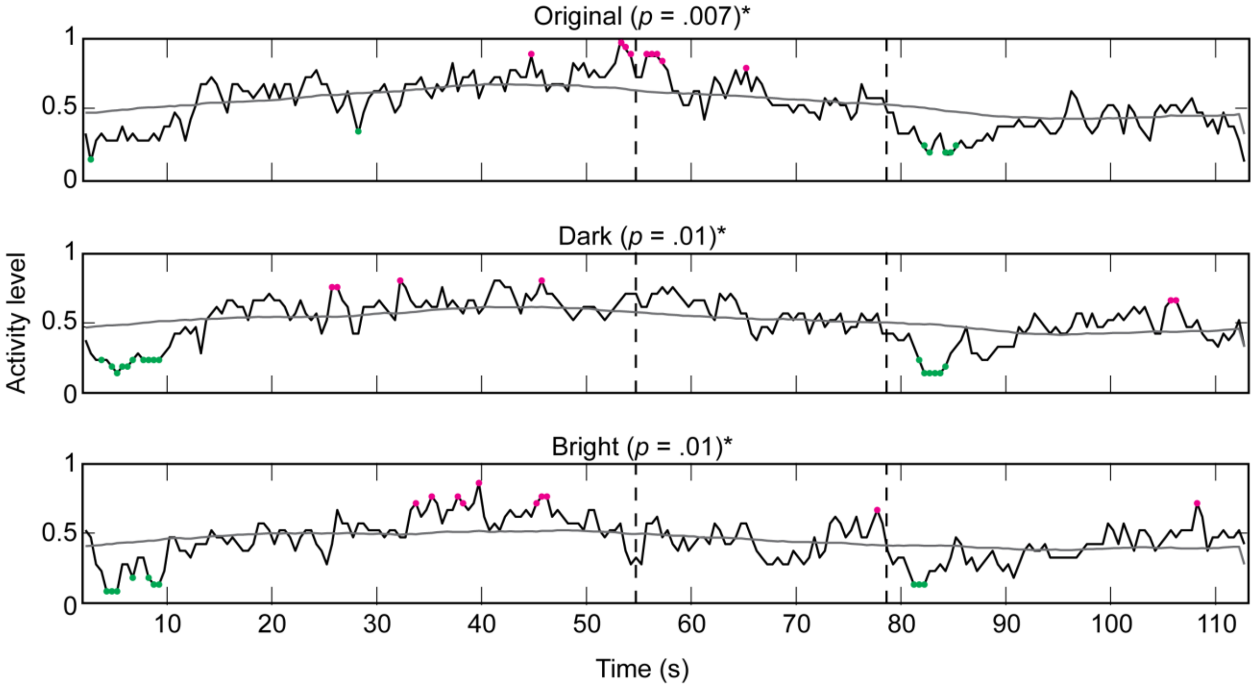

Figure 5-9. Heart rate activity (black) above a threshold of 1.5 for the original, dark, and bright versions of the Debussy excerpt. In comparison to the median of alternatives (grey), highlighting in pink and green indicates significant moments of local activity above and below, respectively. Vertical lines indicate sectional markers. Asterisks indicate coordination at $p < .05$.

For the measures related to valence, the behavioural valence ratings and zygomaticus activity indicate positively valenced emotional responses that increased in magnitude throughout. For the original and dark versions, there were significant moments of local activity for increases in valence ratings in the second section (in parallel with the arousal ratings, described above). The bright version was not coordinated for increases in valence. For valence ratings above the upper bound threshold, almost 100% of participants had activity starting at the onset to the final section across all versions. The zygomaticus (smiling) activity also had significant moments of high activity for the original and dark versions in the final section after the arrival point (Figure 5-10). The activity of the bright version was not significantly different from random activity. The corrugator (frowning) activity did not show coordination for any version.

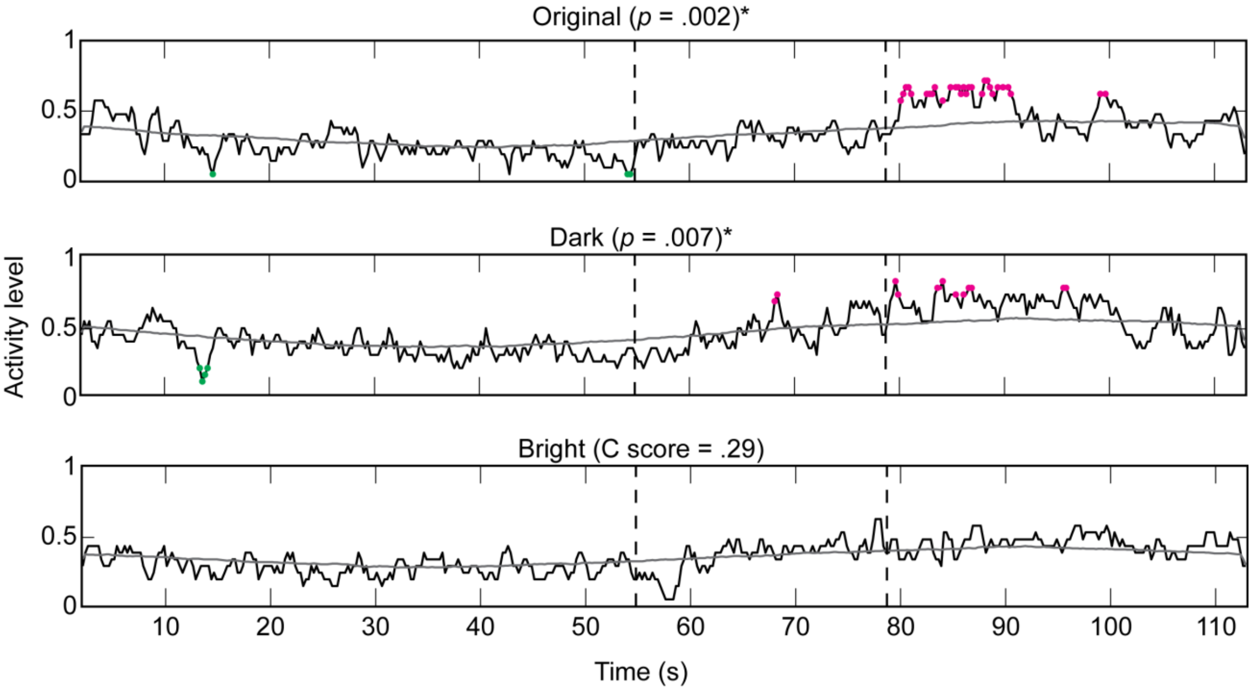

Figure 5-10. EMG zygomaticus activity (black) above a threshold of 3 for the original, dark, and bright versions of the Debussy excerpt. In comparison to the median of alternatives (grey), highlighting in pink and green indicates significant moments of local activity above and below, respectively. Vertical lines indicate sectional markers. Asterisks indicate coordination at $p < .05$.

Given that the responses to the original version were high in arousal and positively valenced, our prediction would be that that emotional responses to the bright version would be more positively valenced compared to the original version. However, the bright version was not coordinated for valence increases, and there were no version differences for valence ratings above the upper bound threshold. The facial EMG results indicate that participants responded during the third section climax with the most zygomaticus (smiling) activity in the original compared to the dark version, with no coordination in the bright version. Therefore, the valence ratings and zygomaticus activity differ across versions, but not in our hypothesized direction.

Vaughan Williams excerpt

The Vaughan Williams excerpt, which begins the first movement of the *London Symphony,* features a sudden addition orchestral gesture. All of the p-values with at least one version coordinated ($p < .05$) are listed in Table 5-7. As discussed above in relation to Figures 5-6 and 5-7, there was a spike in increasing arousal activity directly before and after the sudden addition. Similar to the results of the Debussy excerpt, the heart rate activity was significantly coordinated (Figure 5-11), but not respiration rate or skin conductance. Participants' heart rates dropped at the beginning of the excerpt and after the sudden addition, likely related to orienting responses. During the anticipatory signal (110-135 s), there were significant increases in local heart rate activity across all three versions.

Table 5-7. Audience coordination of emotional response measures for various activity types and thresholds for the Vaughan Williams excerpt (original, dark, and bright versions). Asterisks indicate $p < .05$.

Measure	Activity	Threshold	Original	Dark	Bright
Arousal	Increases	2%	.001*	.002*	.001*
	Decreases	3%	.001*	.003*	.04*
	Upper bound	0.6	.001*	.001*	.001*
	Lower bound	0.3	.004*	.009*	.08
RR	Upper bound				
	Lower bound				
HR	Upper bound	1.5	.05*	.004*	.05*
	Lower bound	-1.5	.05*	.04*	.03*
SC	Upper bound				
Valence	Increases	3%	.03*	.12	.75
	Decreases	3%	.001*	.08	.003*
	Upper bound	0.6	.006*	.41	.31
	Lower bound	0.3	.03*	.04*	.24
EMGz(+)	Upper bound	4	.02*	.05*	.06
EMGc(-)	Upper bound	2.5	.04*	.37	.008*

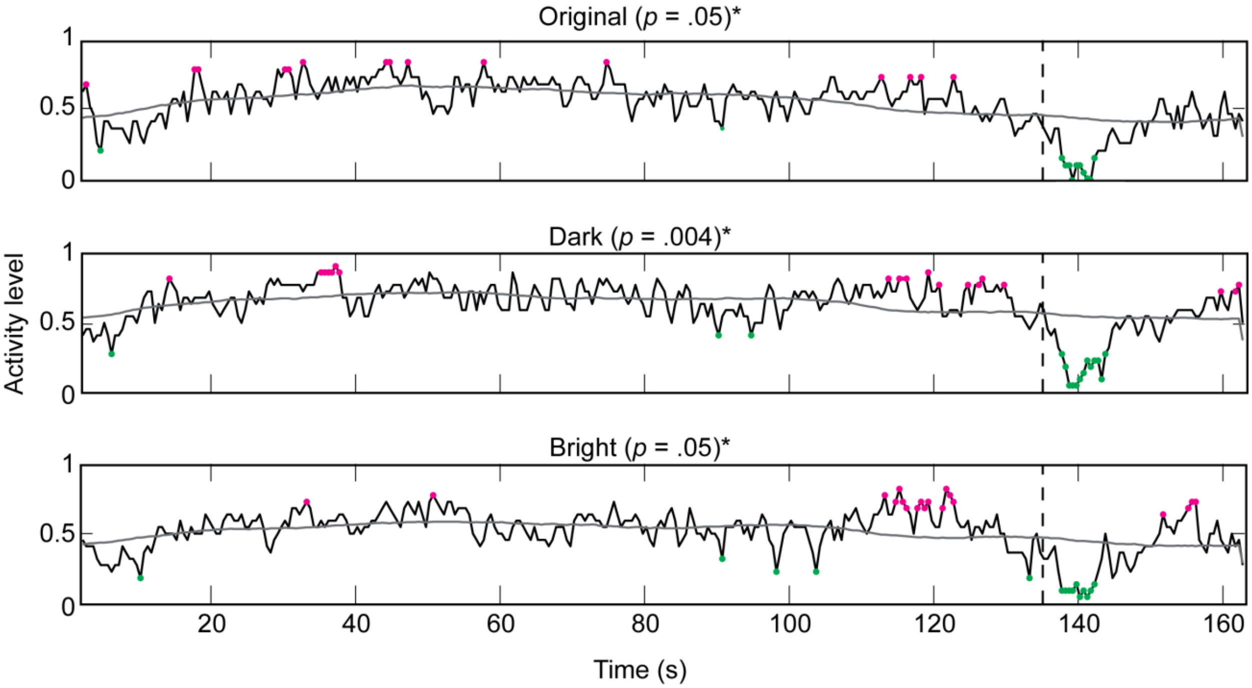

Figure 5-11. Heart rate activity (black) above a threshold of 1.5 for the original, dark, and bright versions of the Vaughan Williams excerpt. In comparison to the median of alternatives (grey), highlighting in pink and green indicates significant moments of local activity above and below, respectively. Vertical line indicates moment of sudden addition. Asterisks indicate coordination at $p < .05$.

For valence ratings, the activity was coordinated only for the original version. In the original version, over half of the participants rated positive valence above the threshold of 0.6 within the first 10 seconds of the excerpt and stayed in this range for the first 120 seconds. Local moments of significant high activity above the positive threshold occurred during the anticipatory signal, but suddenly dropped after the sudden addition, with significant activity below the negative threshold of 0.3. The bright and dark versions showed similar trends, but did not reach significance.

High corrugator activity (associated with frowning) corresponded with the negative valence ratings after the sudden addition for the original and bright versions (Figure 5-12). The corrugator activity for the dark version did not show audience coordination. The original version had significant moments of increasing corrugator activity during the anticipatory signal as well, but the activity of the bright version was localized after the sudden addition, with more activity compared to the original version. The zygomaticus (associated with smiling) also had significant moments of high activity after the sudden addition for the original and dark versions (Figure 5-13), but the activity of the bright version was not significantly coordinated.

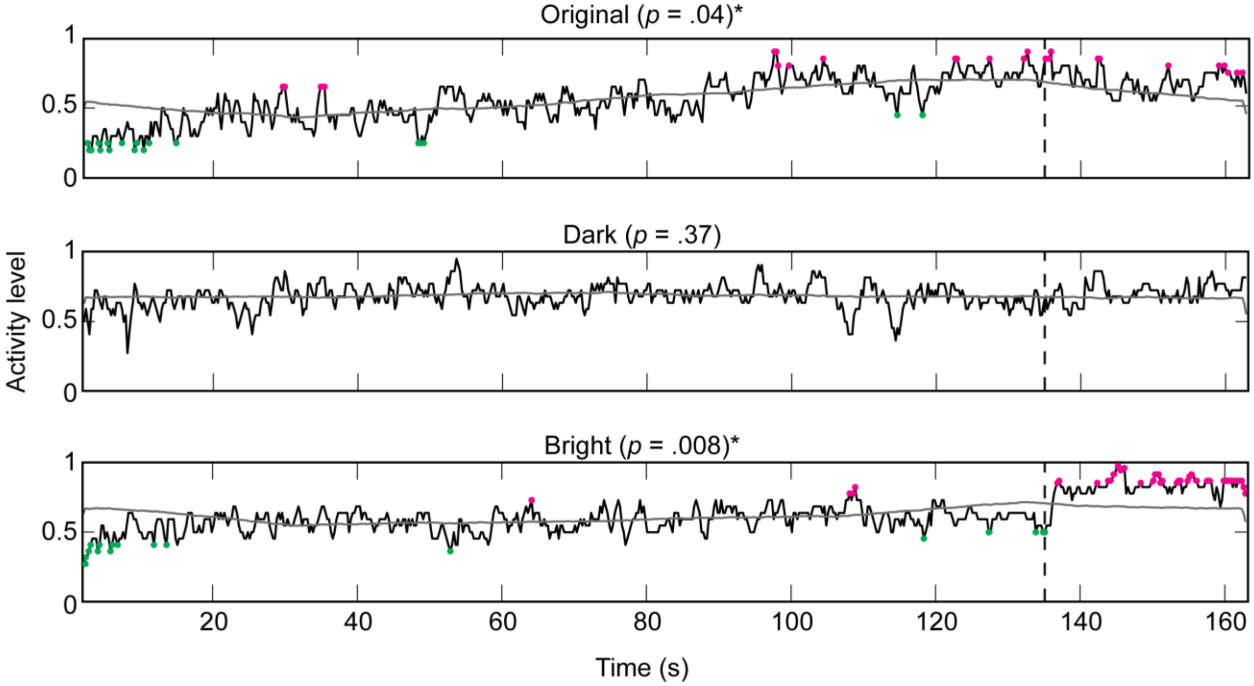

Figure 5-12. EMG corrugator activity (black) above a threshold of 2.5 for the original, dark, and bright versions of the Vaughan Williams excerpt. In comparison to the median of alternatives (grey), highlighting in pink and green indicates significant moments of local activity above and below, respectively. Vertical line indicates moment of sudden addition. Asterisks indicate coordination at *p* < .05.

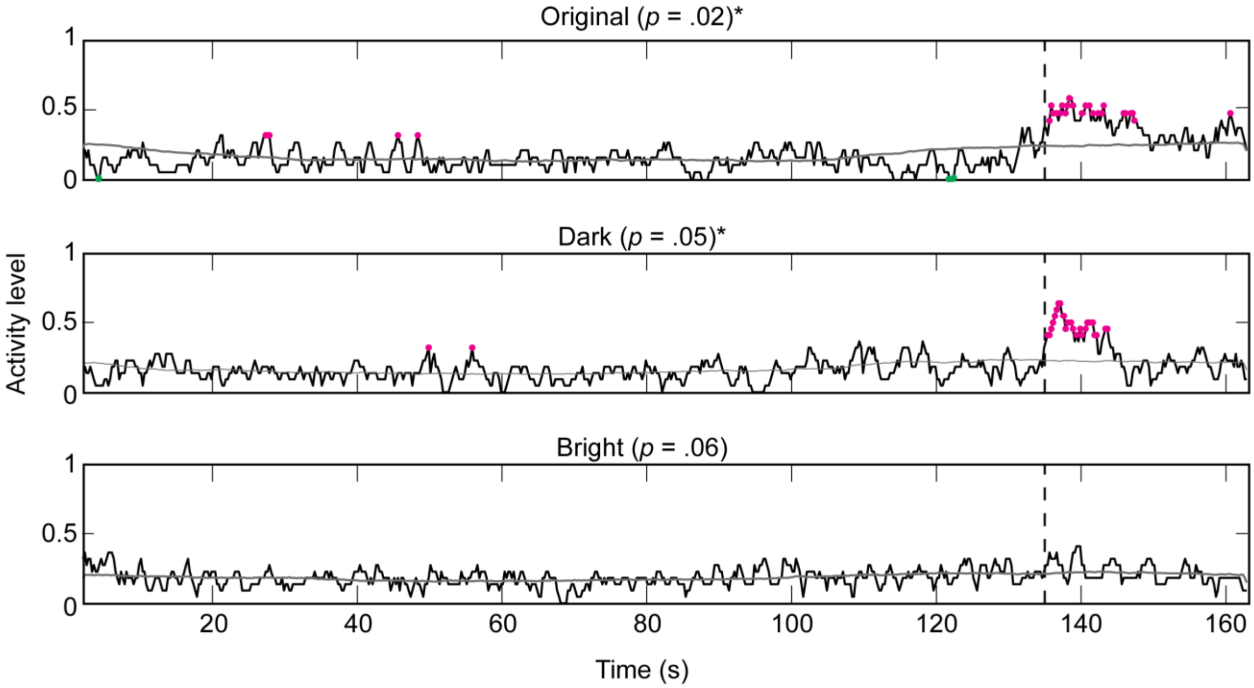

Figure 5-13. EMG zygomaticus activity (black) above a threshold of 4 for the original, dark, and bright versions of the Vaughan Williams excerpt. In comparison to the median of alternatives (grey), highlighting in pink and green indicates significant moments of local activity above and below, respectively. Vertical line indicates moment of sudden addition. Asterisks indicate coordination at $p < .05$.

Given that there was high activity for the corrugator and zygomaticus, representing both positively and negatively valenced responses, these results may indicate that the emotional responses were mixed after the sudden addition for the original version. Following our initial hypotheses, the bright version appears to have caused more negatively valenced emotions compared to the original, with congruent negative valence ratings and high corrugator activity after the sudden addition. The dark version also appears to have mixed responses, due to the negative valence ratings and the high zygomaticus activity; however, also following our hypothesis, the responses are slightly more positively valenced than the original version, since there was only significant zygomaticus activity (not corrugator) after the sudden addition.

Another explanation for the apparent disconnect between the negative valence ratings and facial EMG activities involves an emotional response of disgust; several studies have found that during highly unpleasant pictures and sounds zygomaticus activity co-occurred with corrugator activity, involving scowling of the brow muscles and tightening of the cheek and eye muscles (*orbicularis oculi*) (Bradley and Lang 2007, 592). The disgust explanation, however, is limited in that it is only applicable to the original version, which showed both zygomaticus and corrugator muscle tension, whereas the dark and bright versions featured significant moments for the zygomaticus or corrugator, respectively.

Holst excerpt

The Holst excerpt, from the ending of the movement "Uranus: The Magician" from *The Planets,* features a sudden reduction orchestral gesture. All of the *p*-values with at least one version coordinated ($p < .05$) are listed in Table 5-8. The arousal ratings across all versions followed the structure of the excerpt: high increasing activity occurred for the first 10 seconds and plateaued above the upper bound threshold of 0.7 until the drop-off point, where ratings plummeted and fell below the lower bound threshold of 0.3 (low arousal) for the remainder of the excerpt. The only exception is the dark excerpt for decreasing activity, which showed the same trends as the other versions but did not reach significance, likely due to the less rapid decreases after the sudden reduction. Both the heart rate and skin conductance activities were significantly coordinated and represented orienting responses in relation to the high intensity music at the beginning of the excerpt, but not for the dramatic orchestral reduction. The heart rate dropped at the beginning of the piece and peaked at the end of the excerpt. Previous studies have found chills and increases in skin conductance in response to the abrupt textural contrast from full forces to a soloist or small group (Guhn, Hamm, and Zentner 2007; Sloboda 1991).[25] However, significant moments of

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[25] See also Goodchild et al. (2016) [Chapter 3].

increasing skin conductance only occurred at the onset of the excerpt, the activity being low otherwise.

Table 5-8. Audience coordination of emotional response measures for various activity types and thresholds for the Holst excerpt (original, dark, and bright versions). Asterisks indicate $p < .05$.

Measure	Activity	Threshold	Original	Dark	Bright
Arousal	Increases	2%	.001*	.001*	.005*
	Decreases	3%	.001*	.19	.001*
	Upper bound	0.7	.001*	.001*	.001*
	Lower bound	0.3	.001*	.004*	.001*
RR	Upper bound				
	Lower bound				
HR	Upper bound	1	.001*	.001*	.001*
	Lower bound	-1.5	.04*	.001*	.001*
SC	Upper bound	2.5	.005*	.02*	.002*
Valence	Increases				
	Decreases	2%	.02*	.001*	.63
	Upper bound				
	Lower bound	0.2	.32	.27	.01*
EMGz(+)	Upper bound	5.5	.002*	.03*	.001*
EMGc(-)	Upper bound				

For valence ratings, the activity was low throughout. Only the original and dark versions showed coordination for decreases, with significant moments of decreasing activity for the first 20 seconds of the excerpt, particularly for the dark version (see Figure 5-14).[26] For the lower bound threshold, only the bright version was coordinated, with significant moments of local activity at a later point between 20 and 30 seconds. Therefore, the bright and dark versions were rated more negatively than the original version, but not at the same moments. Unlike the Vaughan Williams excerpt with a large spike in activity directly before and after the moment of sudden addition, the drop-off point in the Holst resulted in low increasing and decreasing activity, indicating mixed responses.

For all orchestral versions, there were local moments of significant zygomaticus activity during the first 30 seconds, but the activity was low for the remainder of the excerpt (Figure 5-15).

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[26] In Figure 5-14, the activity-level axis is flipped because it represents decreasing valence ratings.

The burst of zygomaticus activity at the beginning may be related to a startle reflex caused by the onset of the high intensity music; however, the arousal activity (decreases in heart rate and slow rise of skin conductance) points towards an orienting response, which is considered to represent an earlier stage of defensive activation.[27] The corrugator activity was not coordinated for any version. Therefore, there is a disconnect between the negative valence ratings and positive zygomaticus activity at the beginning.

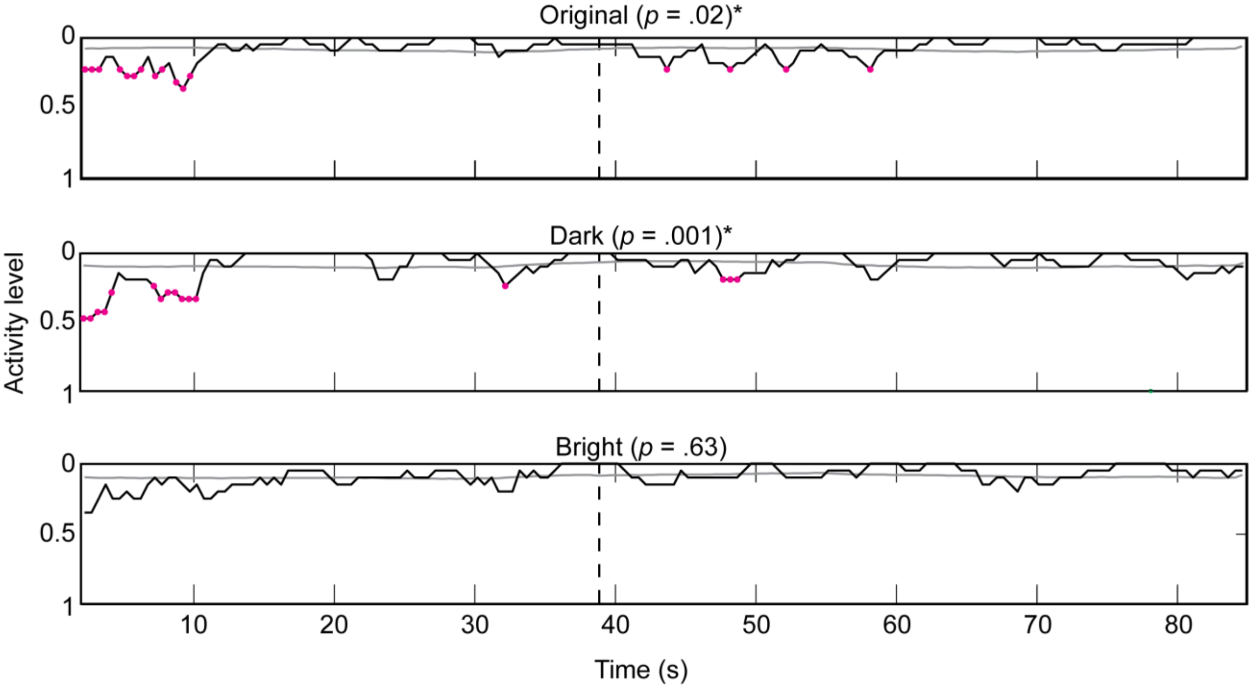

Figure 5-14. Decreasing valence activity (black) above a threshold of 2% for the original, dark, and bright versions of the Holst excerpt. In comparison to the median of alternatives (grey), highlighting in pink and green indicates significant moments of local activity above and below, respectively. Vertical line indicates moment of sudden reduction. Asterisks indicate coordination at *p* < .05.

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[27] See discussion of the defensive cascade in Bradley and Lang (2007).

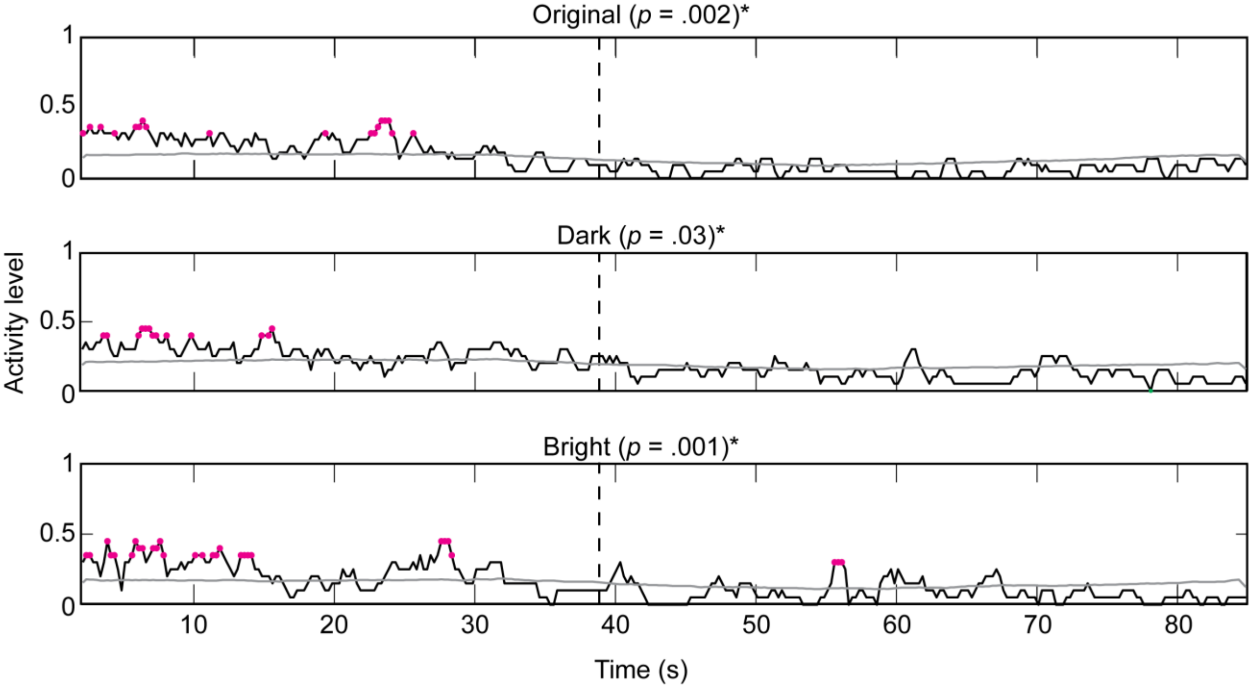

Figure 5-15. EMG zygomaticus activity (black) above a threshold of 5.5 for the original, dark, and bright versions of the Holst excerpt. In comparison to the median of alternatives (grey), highlighting in pink indicates significant moments of local activity. Vertical line indicates moment of sudden reduction. Asterisks indicate coordination at $p < .05$.

Role of context

The hybrid versions of the excerpts were created in order to investigate whether the responses to the same instrumental scoring would vary based on different preceding contexts. For the Debussy excerpt, the recombination occurred progressively starting at one extreme, moving through the original version, and ending at the other extreme. For the Vaughan Williams and Holst excerpts, the sections were divided at the point of the sudden textural change.

We tested the influence of the initial dark scoring on the end of the dark-bright version compared to the fully bright version. Similarly, we tested the influence of the initial bright scoring on the end of the bright-dark version compared to the fully dark version. We predicted that the preceding context would influence the ratings, particularly at the moment of sudden textural change for the Vaughan Williams and Holst excerpts and at the climactic moment in the third section in the

Debussy excerpt, given the strong emotional intensity ratings at these moments in a previous experiment.[28]

There were no differences related to context for the Holst versions. This result is not surprising given the low activity and mixed responses for the valence ratings, the lack of corrugator coordination, and the low activity of the zygomaticus.

For the Debussy excerpt, there were no effects of the context for the valence behavioural ratings; however, the zygomaticus activity differed based on the preceding context. Figures 5-16 and 5-17 compare the zygomaticus activity for the dark and bright-dark versions and the bright and dark-bright versions, respectively. The music within the dashed boxes is identical (the same acoustic signal), but the prior musical context is different. As discussed above, only the original and dark versions had significant audience coordination for zygomaticus activity, with high activity in the third section. The bright version did not show audience coordination. Compared to the dark version, the hybrid bright-dark version was not significantly coordinated and therefore, did not have significant moments of increasing zygomaticus activity in the third section. This result reflects the influence of the bright initial context. In comparison to the bright version, the dark-bright version was significantly coordinated and had local moments of significant activity at the end, suggesting that the preceding dark context influenced the zygomaticus activity during the final bright section.

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[28] (Goodchild, Wild, and McAdams 2016) [Chapter 3].

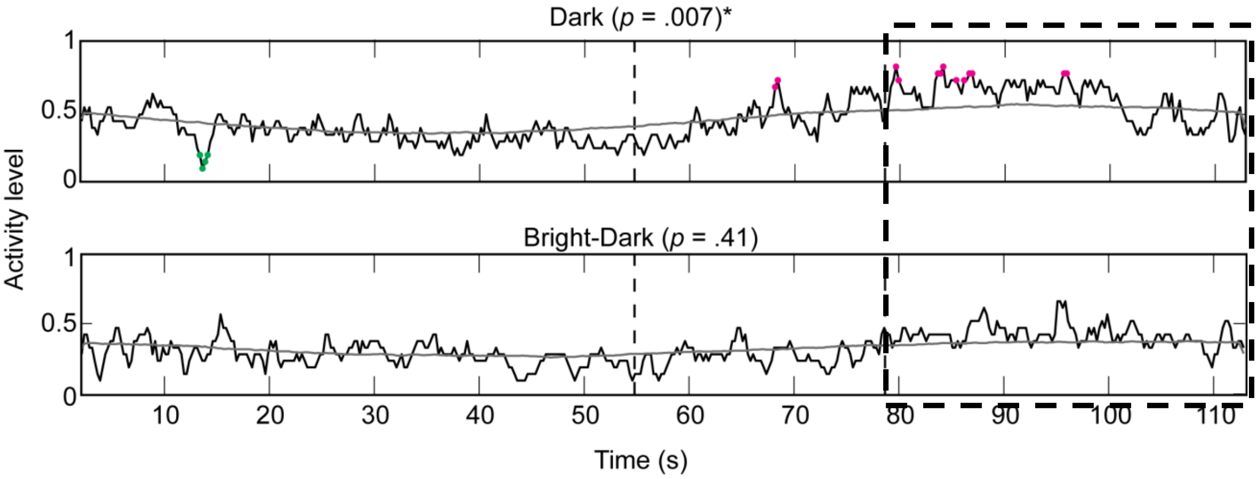

Figure 5-16. EMG zygomaticus activity (black) above a threshold of 3.5 for the dark and bright-dark versions of the Debussy excerpt. In comparison to the median of alternatives (grey), highlighting in pink and green indicates significant moments of local activity above and below, respectively. Vertical lines indicate sections. Asterisks indicate coordination at *p* < .05. The responses within the dotted box are to the same music.

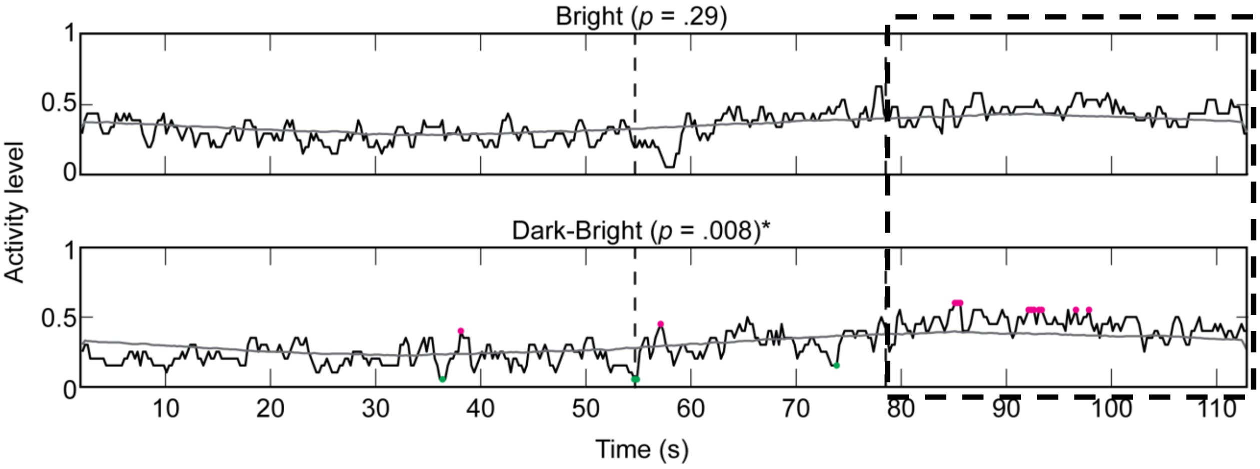

Figure 5-17. EMG zygomaticus activity (black) above a threshold of 3.5 for the bright and dark-bright versions of the Debussy excerpt. In comparison to the median of alternatives (grey), highlighting in pink and green indicates significant moments of local activity above and below, respectively. Vertical lines indicate sections. Asterisks indicate coordination at *p* < .05. The responses within the dotted box are to the same music.

For the Vaughan Williams excerpt, the zygomaticus activity showed clear contextual effects (see Figures 5-18 and 5-19). Again, the music within the dotted boxes is identical, but the preceding context differs. As described above, the bright version was not significantly coordinated and had low activity throughout. Compared to the dark version, the hybrid bright-dark version was not significantly coordinated and thus lacks significant moments of increasing zygomaticus activity after the sudden addition (Figure 5-18). This result reflects the influence of the initial bright context. In comparison to the bright version, the dark-bright version was coordinated and featured significant moments of local activity after the sudden addition (Figure 5-19). Therefore, the preceding dark context had an impact on the response after the sudden addition (increased activity level) for the dark-bright version in comparison to the fully bright version.

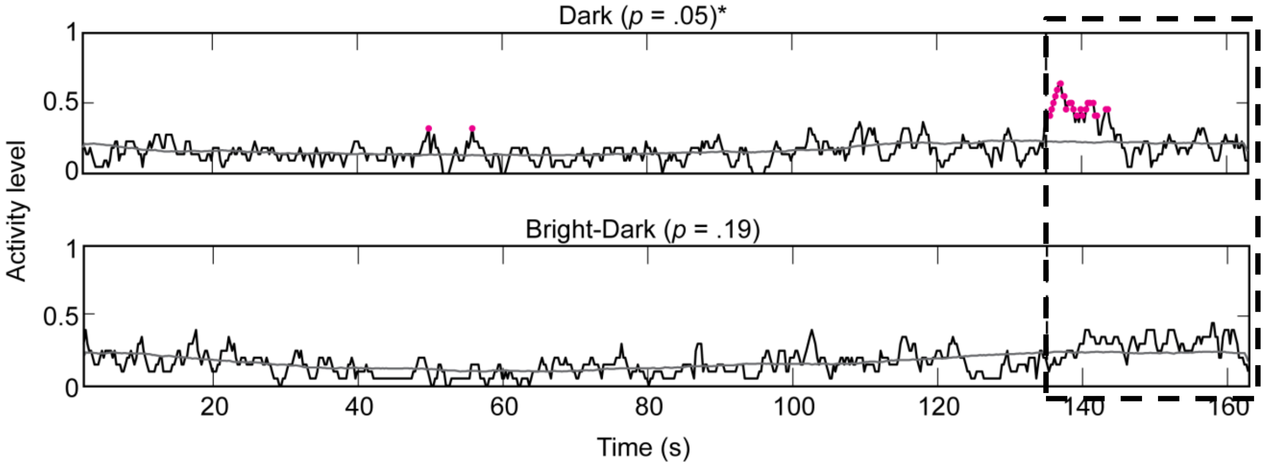

Figure 5-18. EMG zygomaticus activity (black) above a threshold of 4 for the dark and bright-dark versions of the Vaughan Williams excerpt. In comparison to the median of alternatives (grey), highlighting in pink and green indicates significant moments of local activity above and below, respectively. Vertical line indicates moment of sudden addition. Asterisks indicate coordination at *p* < .05. The responses within the dotted box are to the same music.

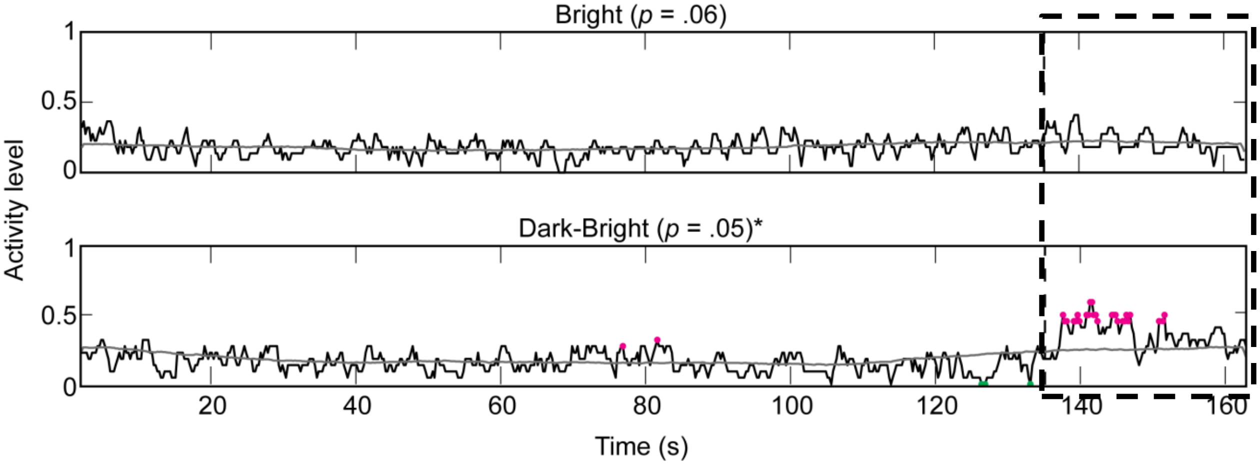

Figure 5-19. EMG zygomaticus activity (black) above a threshold of 4 for the bright and dark-bright versions of the Vaughan Williams excerpt. In comparison to the median of alternatives (grey), highlighting in pink and green indicates significant moments of local activity above and below, respectively. Vertical line indicates moment of sudden addition. Asterisks indicate coordination at *p* < .05. The responses within the dotted box are to the same music.

DISCUSSION

To our knowledge, this study is one of the first to investigate emotional responses to ecologically valid stimuli in which a musical parameter of interest was manipulated. Based on associations in orchestration treatises and findings in previous research, our hypothesis related to orchestral brightness predicted that increasing or decreasing the global spectral centroid would affect the valence dimension of listeners' emotional responses based on the level of arousal: brighter versions would augment the response to the extremes along the valence dimension for high arousal emotions, whereas darker versions would augment the response to the extremes along the valence dimension for low arousal emotions. We tested this hypothesis by creating expert reorchestrations to modify the spectral centroid through instrumentation adjustments and by realistically rendering the versions to control for performance timings and dynamic variations, as well as the context of the musical excerpt itself (e.g., harmony, rhythm, melody). Therefore, this interdisciplinary study constitutes a unique research approach that could be used in future to explore the effects of other musical parameters on the listening experience in a systematic manner.

This study is an important addition to research on music and emotion, as it employs the newly developed approach of activity analysis that investigates audience response coordination of continuous measures rather than the use of central tendency measures (e.g., moving average or grand averages). Our results reveal the complexity in the connection between subjective and objective measures of felt emotions. Additionally, the effect of increasing or decreasing spectral centroid on valence responses was not a simple monotonic function as predicted (discussed further below).

Retrospective ratings

The retrospective ratings indicated that experimental procedure did not overly impede on the listening experience as the participants' moods did not change significantly from the beginning to the end of the experiment. The participants reported that the iPod interface was easy to use and the apparatus (iPod and biosensors) was not intrusive on the listening experience. Participants generally had low familiarity for each excerpt and were not more familiar with the original version compared to the reorchestrated versions. However, post hoc tests revealed that the bright version was slightly more familiar than the dark version for the Vaughan Williams excerpt. In terms of preference, participants generally liked the excerpts. Post-hoc tests revealed that the bright version was rated higher than the dark-bright version. The reported chills did not significantly vary across versions. This result was expected given that the structural musical features and dynamics were held constant.

Activity analysis

Behavioural and psychophysiological responses for original, dark, and bright versions

The analyses using activity analysis indicated that there were differences across the within-collection activity for measures of valence to a greater extent than measures of arousal. The arousal ratings generally reflected the dynamic variation of the excerpt across versions. Similarly, heart rate was consistently coordinated, featuring deceleration and acceleration patterns for climactic moments (e.g., the third section of the Debussy, the sudden addition of the Vaughan Williams excerpt, and the beginning of the Holst excerpt). Respiration rate was not coordinated for any version of any excerpt, which was likely related to the response variability across participants. Only the Holst excerpt featured audience coordination for skin conductance, which reflected orienting responses to the onset of the loud march theme.

Although there were differences in valence measures across versions, the magnitude and direction of change did not always reflect the hypotheses. For all versions of the Debussy excerpt, increases in valence ratings occurred in the second section and ratings above the upper bound were found in the climactic third section. Significant moments of increasing zygomaticus activity also occurred in the third section for the original and dark versions. Given the high arousal and positive valence, our prediction would be that the bright (B) version would augment the positive response along the valence dimension over the original (O) version, followed by the dark (D) version, represented as B > O > D. However, the zygomaticus activity was strongest for the original followed by the dark, and was uncoordinated for the bright version (O > D > B).

The valence ratings for the Vaughan Williams excerpt had high activity during the anticipatory signal, but dropped suddenly after the sudden addition for the original version. Given the high arousal and negative valence after the sudden addition, we would predict that the bright version would augment the negative response along the valence dimension for this section (B > O >

D). The corrugator activity matched these predictions with significant moments of localized activity after the sudden addition for the bright version, more diffuse activity for the original version, and no coordination for the dark version (B > O > D). However, the interpretation is complicated by the concurrent zygomaticus activity after the sudden addition for the original and dark versions—a finding which could indicate mixed feelings or even disgust for the original version.

For the Holst excerpt, the valence rating activity differed across versions. The dark version had more significant moments of decreasing valence ratings compared to the original version at the very beginning of the excerpt. The bright version also had significant moments of local activity below the negative valence threshold, but the original version was not coordinated for this measure. Therefore, the direction of activity of the valence ratings across versions does not reflect the hypotheses (D/B > O). Additionally, the facial EMG activity and valence ratings were incongruent. Although there were extensive negative valence ratings, the corrugator activity was not coordinated for any version. Local moments of significant zygomaticus activity occurred during the first 30 seconds for all versions, likely reflecting orienting responses.

Based on connotations in orchestration treatises and empirical studies on individual instrument timbres, we hypothesized that brighter versions of excerpts would augment the response to the extremes along the valence dimension for high arousal emotions, whereas darker versions would augment the response to the extremes along the valence dimension for low arousal emotions. These predictions were not confirmed (as discussed above). One potential explanation may be that the hypotheses apply for isolated timbres, but not for instrumental ensembles. The complex musical fabric may interact with innumerable musical parameters, resulting in unpredictable responses to the climactic musical moments.

Recent research on instrumental affect may also shed some light on this issue. Douglas's (2015) research indicates that participants' perceived valence ratings of single instrument sounds reflect an inverted U-shape based on pitch register. For string, woodwind, and brass families, the most positive ratings were for instruments on D#4 (311 Hz). From this point, the valence ratings become more negative as the pitch register decreases to D#1 (38.9 Hz) or increases to D#7 (2489 Hz). Given that the instrument's pitch has direct implications for the spectral centroid, one could extrapolate that the perceived valence increases as a function of the spectral centroid within a certain frequency range, after which point the perceived valence decreases. The bright reorchestrations may have shifted the spectral centroid of the instrumental ensemble to the extremes where the valence is perceived as more negative, resulting in negative valence ratings. Douglas's findings could explain why the bright version of the Debussy excerpt was not coordinated for the zygomaticus activity, but the original and dark versions had high activity. Similarly, the negative valence ratings for both extreme low- and extreme high-register instruments potentially explain why the bright and dark versions of the Holst excerpt were rated more negatively than the original version. Extending Douglas's research to instrumental ensembles is required to verify this interpretation. Additionally, further research is needed in terms of the connections between perceived and felt valence, as the relationship is not always straightforward (Gabrielsson 2002).

Connection between self-report ratings, psychophysiology, and facial EMG

Overall, the results indicate a disconnect among the behavioural ratings, psychophysiology, and facial EMG activity. Therefore, the coordination of components in the componential approach to emotion may be overstated. Although studies have found coordination between two components, few studies have found synchronized responses across all three components in relation to music. One example is Lundqvist et al. (2009), who found that more feelings of happiness, greater skin conductance, and increased zygomaticus facial muscle activity were associated with happy music compared to sad. In contrast, Grewe et al. (2007) found that the components were not synchronized during listening, which they interpreted to indicate that genuine emotions were not induced. However, recent research has shown that these components may not be completely coordinated in emotional responses outside of musical contexts as well (Niedenthal, Krauth-Gruber, and Ric 2006; Hunter and Schellenberg 2010).

The incongruent activity of the behavioural ratings and facial EMG may be interpreted in several ways. The presence of zygomaticus activity during music rated negatively for valence may result from its susceptibility to cross-talk given its close proximity to several other facial muscle groups, including *buccinator, masseter,* and *zygomaticus minor* (Larsen, Norris, and Cacioppo 2003). Curiously, several studies have found that the sensitivity of the zygomaticus was inferior to the corrugator: valence had a stronger effect on the corrugator than the zygomaticus in tasks with words, pictures and sounds,[29] as well as musical excerpts (Roy et al. 2009). The difference in findings between the current study and previous ones may be related to the application of activity analysis to measure response coordination in contrast to calculating mean values. The potential for the zygomaticus activity to be masked by interpersonal differences in averaged responses should not be discounted.

The issue related to the incongruent responses between the valence ratings and facial EMG could also suggest the existence of mixed emotions, which cannot be represented on a two dimensional model with positive and negative valence as one bipolar dimension. Cacioppo and Bernston's (1994) evaluative space model proposes separate and distinct components of positivity and negativity, allowing for their coactivation (Norris et al. 2010). Positive affect is linked with appetitive motivation, whereas negative affect is linked with aversive motivation. Because these dimensions are independent, increasing one does not necessarily have an effect on the other. A

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[29] Larsen, Norris and Cacioppo (2003) found that increases in positive affect (holding negative affect at 0) inhibited activity over the corrugator, whereas increases in negative affect (holding positive affect at 0) had little effect on zygomaticus.

bivariate valence dimension could explain the mixed responses to the sudden addition of the Vaughan Williams excerpt (high activity for both zygomaticus and corrugator for original version) and the sudden reduction of the Holst excerpt (both increasing and decreasing valence ratings).

In the previous exploratory experiment, the reductive excerpts featured a lingering effect of high emotional intensity, despite the reduction of instrumental forces, dynamics, and other musical parameters.[30] The current study reused the Holst excerpt as a stimulus, and the performance interpretation was based on the same recording. Contrary to the former study, high arousal ratings occurred for the first section until the drop-off point and then ratings plummeted for the remainder of the excerpt. It is unclear why there was such a strong divergence between the two studies. A potential explanation is that dividing the continuous response into two dimensions on the iPod may have increased the cognitive load on the participants in comparison to the slider with a single dimension. Another possibility is that ratings of emotional intensity may have tapped into another dimension (e.g., tension) that is not captured in the arousal dimension.

Previous studies indicated that abrupt textural contrast from full forces to a soloist or subgroup can induce chills, marked by increases in skin conductance (Guhn, Hamm, and Zentner 2007; Sloboda 1991).[31] An issue in the present study is that this feature in the Holst excerpt was not associated with significant moments of increasing skin conductance. Additionally, the heart rate featured orienting responses in relation to the high intensity music at the beginning of the excerpt, but not for the dramatic orchestral reduction. One potential explanation is that the sudden onset of the excerpt caused the first stage of defensive activation involving heightened attention before an overt fight-or-flight responsive reflex, which then drowned out the response to the rest of the excerpt.

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[30] (Goodchild, Wild, and McAdams 2016) [Chapter 3].

[31] A prior exploratory study also found high emotional intensity for excerpts featuring a sudden reduction orchestral gesture (Goodchild, Wild, and McAdams 2016) [Chapter 3].

Hybrid versions

The investigation of the hybrid versions compared to the fully dark or bright versions revealed that the emotional reactions to the same acoustical signal were influenced by differing preceding contexts in both the Debussy and Vaughan Williams excerpts. If the prior music was dark, high EMG zygomaticus activity occurred at the climactic moment, regardless of whether the moment was scored as dark or bright. Similarly, if the previous music was bright, the activity was not coordinated for both the fully bright and bright-dark versions. Based on this result, we suggest that the role of bright and dark instrumentation on emotional response appears to be robust and long-lasting.

This finding highlights a major issue in past empirical studies of considering only the immediate musical context when investigating the links between musical features and emotional responses. We have shown that the musical material leading up to an expressive event dramatically shapes the resulting experience. Additionally, the findings reveal that orchestral or timbral musical features can markedly influence facial affective responses.

Limitations of the study and future work

In this study, we used activity analysis to investigate within-collection coordination for response activities of behavioural and psychophysiological measures. We also plan on investigating the alternating coordination activity of the increasing and decreasing arousal and valence ratings, which would reveal insights into the interaction of these activities. Another potential area of research concerns the differences in coordination between the musicians and nonmusicians listener groups.

Although not analyzed here, we collected retrospective ratings for GEMS, 3-dimensional, and basic emotion models after each stimulus. Investigation into the intersection between self-report ratings and psychophysiology/facial EMG may disentangle the complexities of the emotional responses and potentially assist in interpreting the experience of mixed emotions discussed above.

One limitation of this study was the use a single performance interpretation for all of the versions of a particular excerpt. The DOSim system provides an exceptional opportunity to manipulate expressive parameters, including timing and dynamics. In future, performance features could be systematically tested to investigate how these musical features enhance or diminish the effect under investigation and the resulting emotional responses. In addition to spectral centroid, we have also coded time series parameters of loudness, tempo, instrumental texture, and onset density.[32] These variables, along with other musical features (e.g., harmonic tension), could be used to model the activity of the arousal and valence measures using visualizations or other types of sophisticated time series approaches.

Overall, this study reveals the importance of timbral musical features such as spectral centroid on the listening experience and highlights the need for future work in this area. One major contribution of the study is the finding that emotional responses to dramatic changes in texture as part of an orchestral gesture are directly affected by the brightness or darkness of the preceding context. The results indicate that the effect of brightness on the valence of emotional response is long-lasting, which should be incorporated into theories of orchestration. Associations between brightness and affect should be explored further. Although the arousal dimension does appear to temper the influence of brightness on the valence dimension, the hypothesized outcome occurs only to a certain extent. Extreme brightness appears to reverse this effect and can cause mixed responses in listeners. These research findings challenge the notion of how the physical measure of spectral centroid translates to the perceptual quality of brightness in large instrumental ensembles. In future research, we plan on collecting participants' continuous ratings of perceived brightness to explore

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[32] These features were investigated in a previous exploratory study using visualizations (Goodchild, Wild, and McAdams 2016) [Chapter 3].

their correspondence with the time-varying spectral centroid.[33] These results may assist in clarifying the complex connections between orchestration, perceived brightness, spectral centroid, and emotional valence.

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[33] I wish to thank Emery Schubert for his suggestion for future research.

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CHAPTER 6

CONCLUSION

Overview

This dissertation provides an in-depth study of orchestral gestures through music-theoretical investigations and listening experiments. The focus of the dissertation attempts to fill a void of scholarly attention paid to orchestration and timbre in music research and develops analytical tools to facilitate this effort. Additionally, the aim is to incorporate listeners' perspectives into the theoretical understanding of orchestral gestures and the role of timbre.

In Chapter 2, I contextualized the study of orchestral effects through a historical survey of the development of the orchestra and descriptions in orchestration treatises. Based on these findings, I proposed a typology of orchestral gestures, and analyzed twelve musical examples to examine their evolution over time and to uncover expressive gestural meanings. In Chapter 4, I developed a hypothesis-testing method of recomposition and reorchestration to test specific structural and orchestral features of the sudden reduction gesture and to investigate the connection between orchestral brightness and emotional response.

Two listening experiments were conducted to complement the theoretical investigations. The first experiment explored the evolution of listeners' emotional intensity ratings while listening to orchestral gestures (Chapter 3). The second experiment tested the effect of brightening and darkening through a converging-methods approach, in which subjective and objective measures were collected while participants listened to various versions of excerpts (Chapter 5).

Contributions

One of the most important music-theoretical contributions in the dissertation is the proposed typology of orchestral gestures, defined by large-scale, coordinated changes in instrumentation over time (Chapter 2). The conceptualization of orchestral shaping as a type of musical gesture, rather than as an effect or technique, captures its goal-directed sense of motion and expressive agency as a carrier of emotional force. For the gradual gestures, the overarching expressive trajectory is shaped by the accumulation or abatement of orchestration. The gradual addition gesture embodies a sense of orchestral growth through a process of increasing intensification and expressive force; however, the gradual reduction gestures do not necessarily follow a reverse process of lessening. Late-Romantic composers also create a sense of prolonged stasis by expanding the final stage of abatement. The sudden gestures feature a rapid alteration in the addition or reduction of instruments, but also the resulting timbral change between full forces and a subgroup of the orchestra. Representing a rhetorical shift, the moment of sudden textural change marks a dramatic turning point as part of a large-scale goal-directed motion.

The accompanying listening experiment found distinct emotional response profiles for each of the orchestral gesture types (Chapter 3). Following the increasing growth of instrumental texture and loudness, the emotional intensity ratings climbed steadily for the gradual addition types. The ratings for the sudden addition gestures sharply increased in response to the rapid textural change, peaking toward the end of the excerpt. The responses to the reductive excerpts, both gradual and sudden, feature a plateau of high emotional intensity, despite the decrease or drop-off of other musical features. There was a slight tendency for musicians to anticipate the moment of sudden addition with heightened emotional responses, whereas nonmusicians appeared to follow variations in loudness and tempo.

Chapters 2 and 3 featured the application of a new type of graphical visualization that provides a synoptic view of the gesture by assembling score-based and performance-based musical features. The visualization provides an important music-theoretical tool for analysis of orchestral and timbral features, and their interaction with other musical parameters over time. This is an important step to move beyond traditional anecdotal descriptions of orchestration in traditional music research. The visualization was also extremely useful in observing the evolution of listeners' emotional reactions in response to the orchestral gestures and assisted in interpreting the results of the time series regression analysis.

In Chapter 4, the informal use of recomposition was developed into a hypothesis-testing method, which involves articulating an initial hypothesis about a musical phenomenon, selecting a representative musical example, testing the hypothesis through recomposition, comparative listening to the original and new version(s), and evaluating the results of this process. I argue that this approach provides an accessible entry point for theorists to study orchestration and timbre. The method was used in a case study of a sudden reduction gesture in Bruckner's Symphony 8 and through this process several theoretical implications regarding the gesture were uncovered. First, the point of arrival before the drop-off of texture provides an important turning point and its removal disconnected the material before and after the textural break. Second, the tonal or harmonic instability contributes to the effect of the structural rupture after the sudden reduction. Third, Bruckner's choice of instrumentation in the reduced texture preserves thematic connections and ensures that each layer was audible in terms of tessitura and instrumental timbre.

As Sandell (1995) notes, "This unfortunate lack of scholarship in timbre and orchestration leaves the timbre researcher with few paradigms to prove, disprove, or refine, and the burden of having to start from the beginning" (210). In response to this situation, I drew on snippets of information from orchestration treatises and findings from empirical research on timbre to develop a hypothesis related to the connection between emotional valence and timbral brightness. I predicted that brighter versions would augment the response to the extremes along the valence dimension for high arousal emotions, whereas darker versions would augment the response to the extremes along the valence dimension for low arousal emotions. The method of recomposition was used on a large-scale level to test this hypothesis. Chapter 4 analyzed the strategies used by the composers to adjust the global brightness through adjustments in instrumentation in three orchestral gestures. Additionally, a large-scale listening experiment (Chapter 5) used activity analysis to investigate response coordination of continuous measures across versions. As predicted, the measures of arousal were more invariant across versions in comparison to the measures of valence; however, the direction of the valence response did not always reflect the hypothesis. In several cases, the bright version resulted in a greater negative valence response than predicted. We interpreted this finding in reference to recent work which indicates that perceived valence ratings of individual instrumental sounds vary as a function of fundamental frequency in an inverted-U shape. Therefore the predictions of the hypothesis may hold only for slight increases or decreases in brightness, but not for extreme augmentations.

The research on hybrid reorchestrated versions (Chapter 5) revealed that differing musical contexts leading up to a climactic moment shapes the resulting experience, as the emotional reactions to the same music were influenced by the preceding dark or bright scoring. This finding indicates that the role of orchestral brightness or darkness on the valence of emotional response is long-lasting. Additionally, the result underlines the importance of considering the larger musical context rather than isolated events in research on the connection between musical features and emotional responses.

The dissertation contains several important contributions to music and emotion research, including novel approaches to interdisciplinary scholarship. The visualization tool discussed in Chapters 2 and 3 allows for the analysis of experimental data and music-theoretical parameters of interest. The effect of reorchestration changes on emotional responses was studied in Chapters 4 and 5 by manipulating parameters in the musical stimuli, an approach that is not widely used in the field (Eerola and Vuoskoski 2013). Realistic renderings of the original and reorchestrated versions were made with DOSim, allowing for precise control of real instrument samples and maintaining performance timings and dynamic variations across versions. This research will hopefully open the door to future work in systematic manipulation of musical parameters, including structural, timbral, and performance features. The use of time series approaches, such as time series regression and activity analysis, highlights the need for sophisticated techniques to study listeners' continuous responses in relation to the musical context.

Future work

The dissertation work required the confluence of the research approaches and methods of several domains in order to address interdisciplinary research questions. This study addresses issues in past research by laying the groundwork for a theory of orchestral gestures that incorporates listener experiences, considers the evolution of musical features over time, and focuses on the role of orchestration and timbre. The proposed four types of orchestral gestures provide a starting point for exploration. Future analytical surveys of the repertoire, expanding beyond the late Romantic period, will uncover other types of orchestral gestures. One potential avenue of exploration is the investigation of orchestral gestures in which there are opposing musical features and their resulting expressive effect. These explorations will likely yield important insights into orchestration and how it shapes the musical experience.

The visualizations developed for chapters 2 and 3 incorporate various metrics to study orchestration, including instrumental texture, onset density, and spectral centroid. In future research, the contributions of each instrumental family, or even each instrument, could be assessed by separately rendering these channels from the DOSim environment and extracting the physical measures individually for analysis. By doing so, the role of the textural and timbral parameters could be separated in order to understand their interaction. Other musical-feature overlays, such as phrase structure and harmonic tension, could also be included to investigate how these features support or conflict with other musical processes. In addition, expressive factors of performance timing and dynamic changes could be examined to determine their role in shaping the expressive trajectory of the orchestral gestures.

Given the complexity of timbre as a multidimensional phenomenon, research on the connection between brightness and emotional valence only scratches the surface of the potential in this area. The research findings in chapter 5 challenge the notion of how the physical measure of spectral centroid translates to the perceptual quality of brightness in large instrumental ensembles, and how variations in brightness in turn affect the valence of emotional responses. Future work could explore the correspondence between participants' ratings of perceived brightness and spectral centroid. By doing so, the complex connections between orchestration, perceived brightness, spectral centroid, and emotional valence may begin to be disentangled.

The aim of the dissertation work is to point other researchers in the direction of orchestral gestures as a fruitful area of study, to offer analytical tools to facilitate the study of orchestration, and to promote collaboration with composers and theorists in the future. I believe future interdisciplinary research has the capacity to change the way in which researchers and composers understand orchestration.

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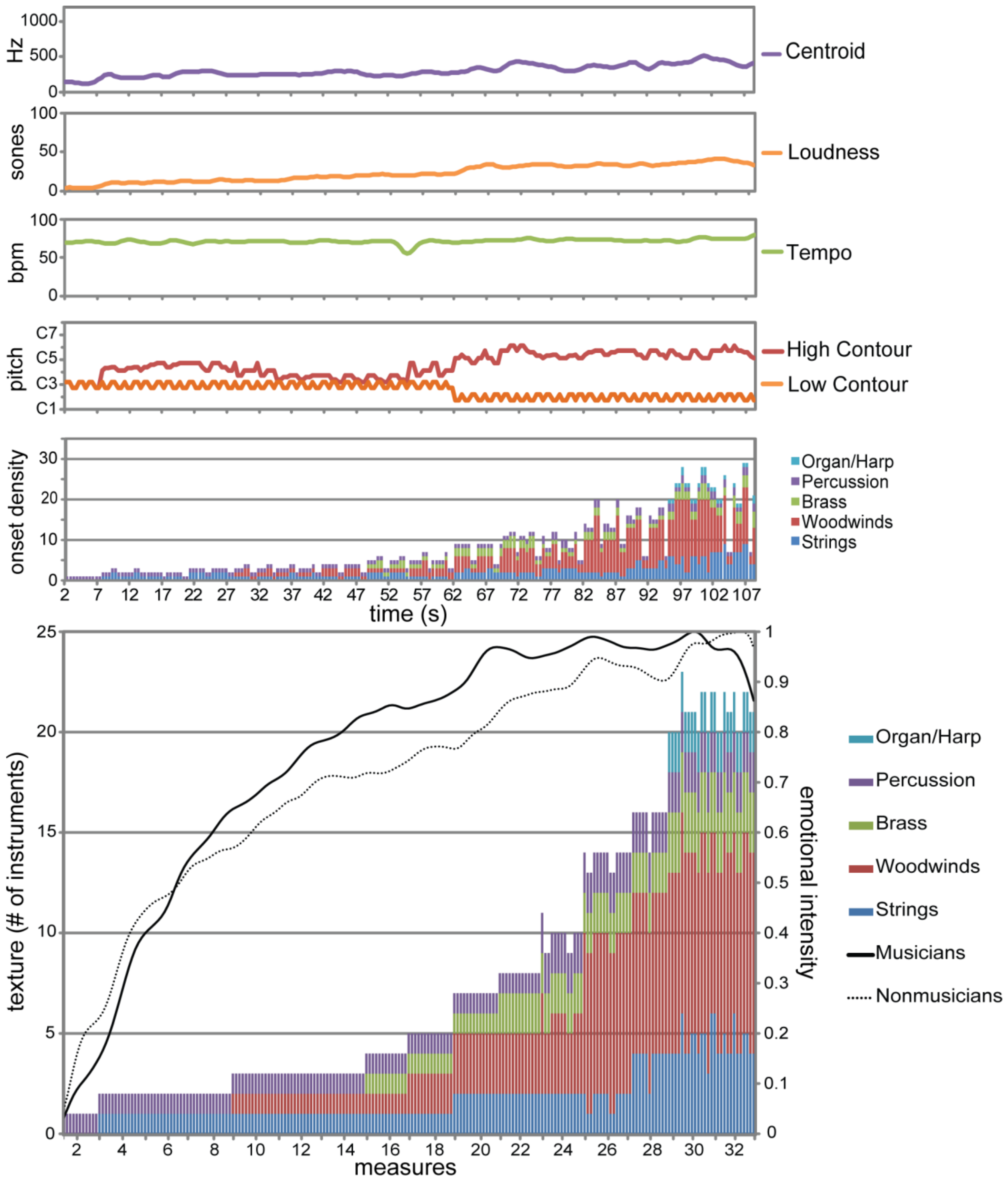
APPENDIX A

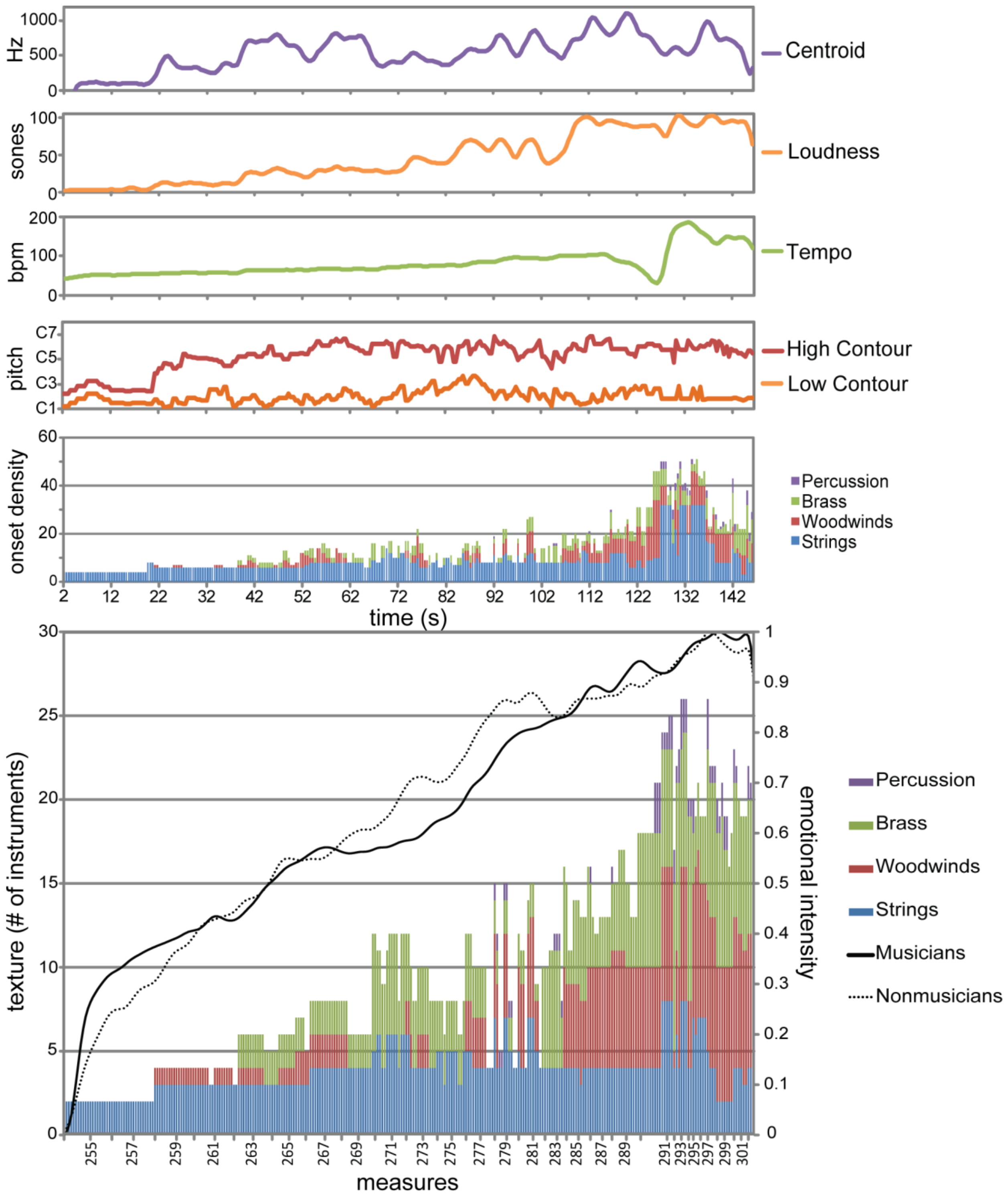
VISUALIZATIONS OF MUSICAL EXCERPTS

The following 12 visualizations are introduced and explained in detail in Chapters 2 and 3. Each visualization contains three score-based features (instrumental texture, onset density, and contour) and three performance-based features (loudness, spectral centroid, and tempo). The emotional intensity slider ratings represent the average ratings for the musician and nonmusician listeners. The x-axis indicates both the measure numbers and the time in seconds from the beginning of the excerpt. Specific recoding details about each excerpt are reported in Tables 2-1 and 3-1.

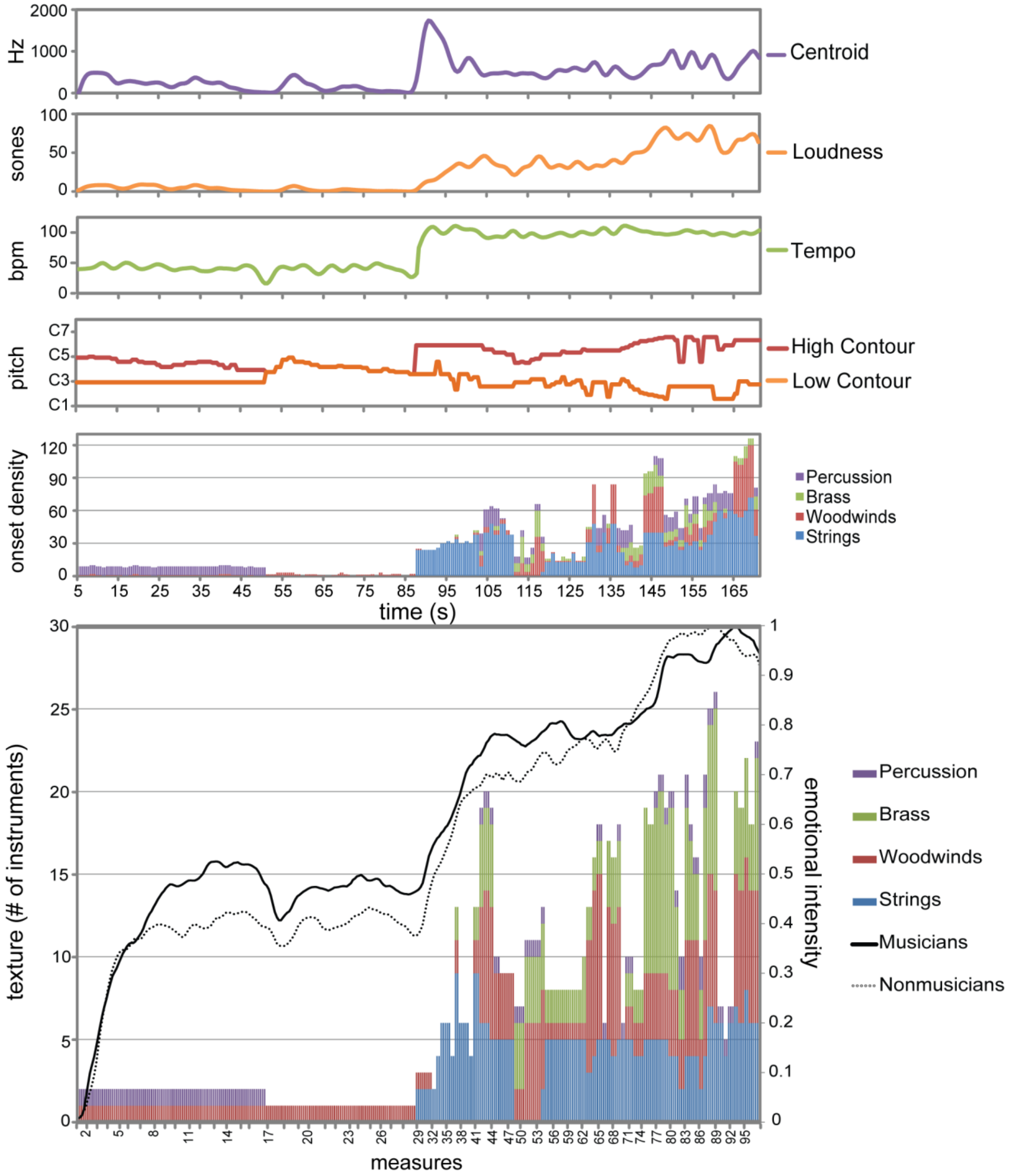
1. Mahler, Symphony 1, III, mm. 1-32



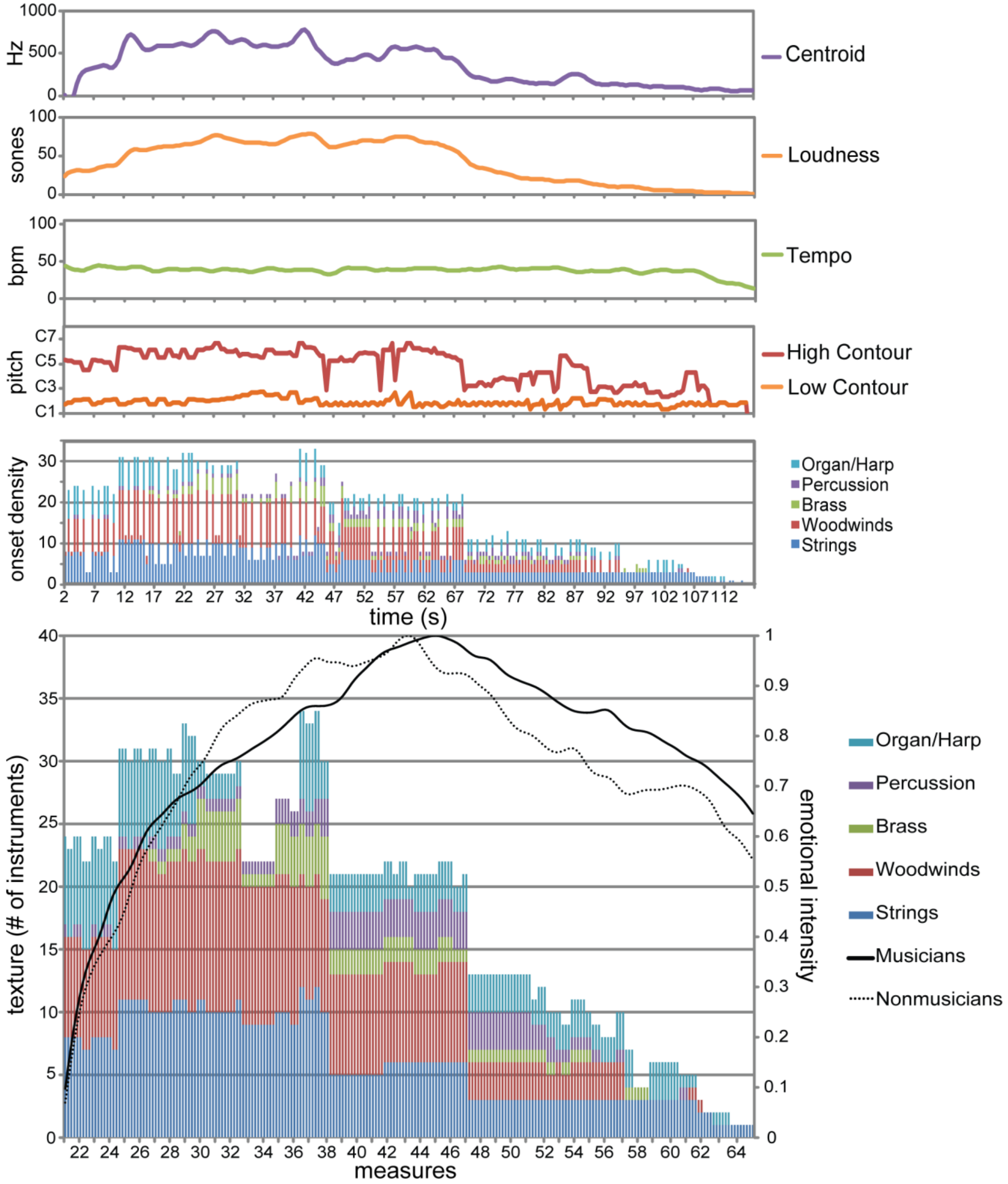
2. Mahler, Symphony 2, I, mm. 254-302



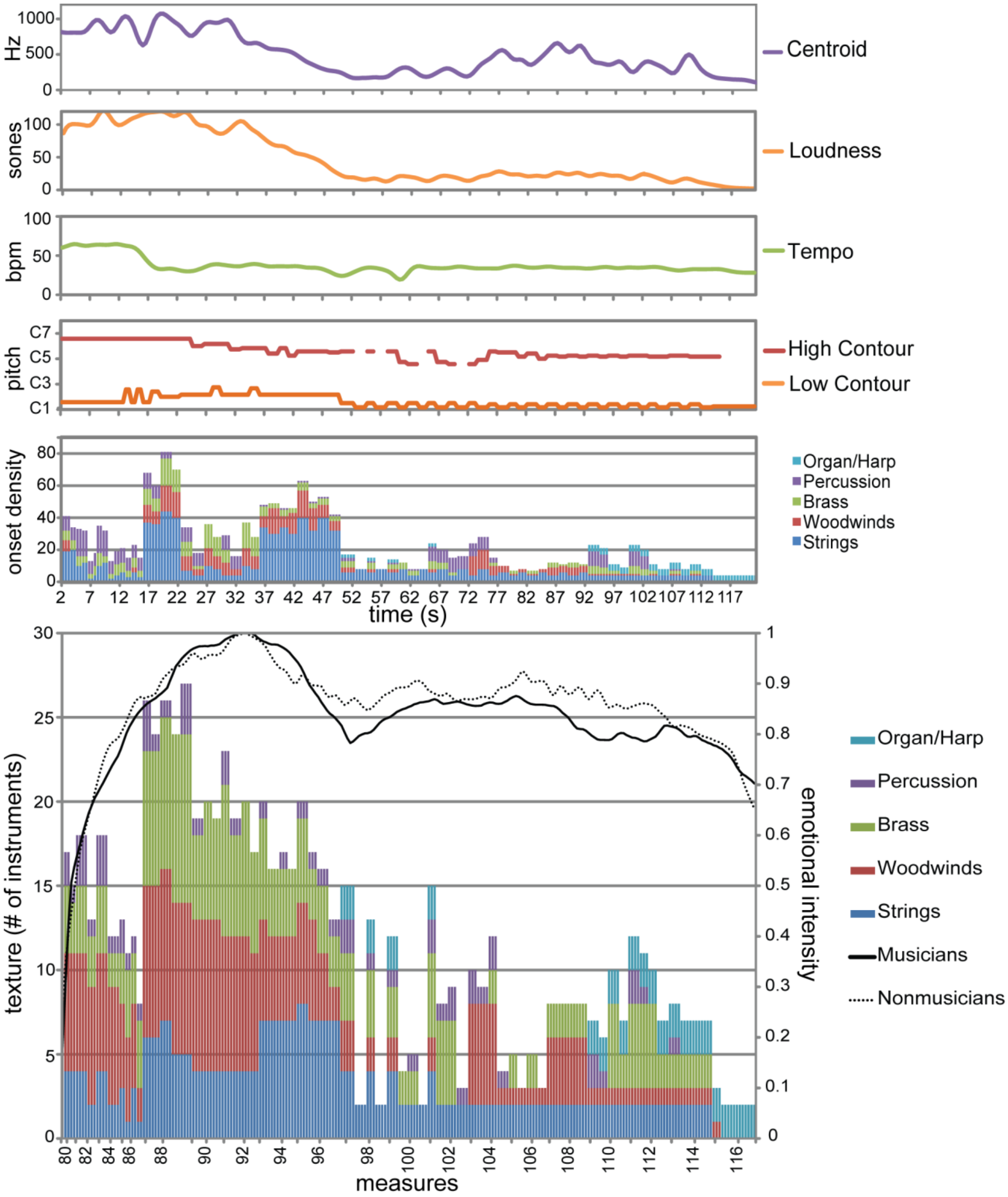
3. Sibelius, Symphony 1, I, mm. 1-96



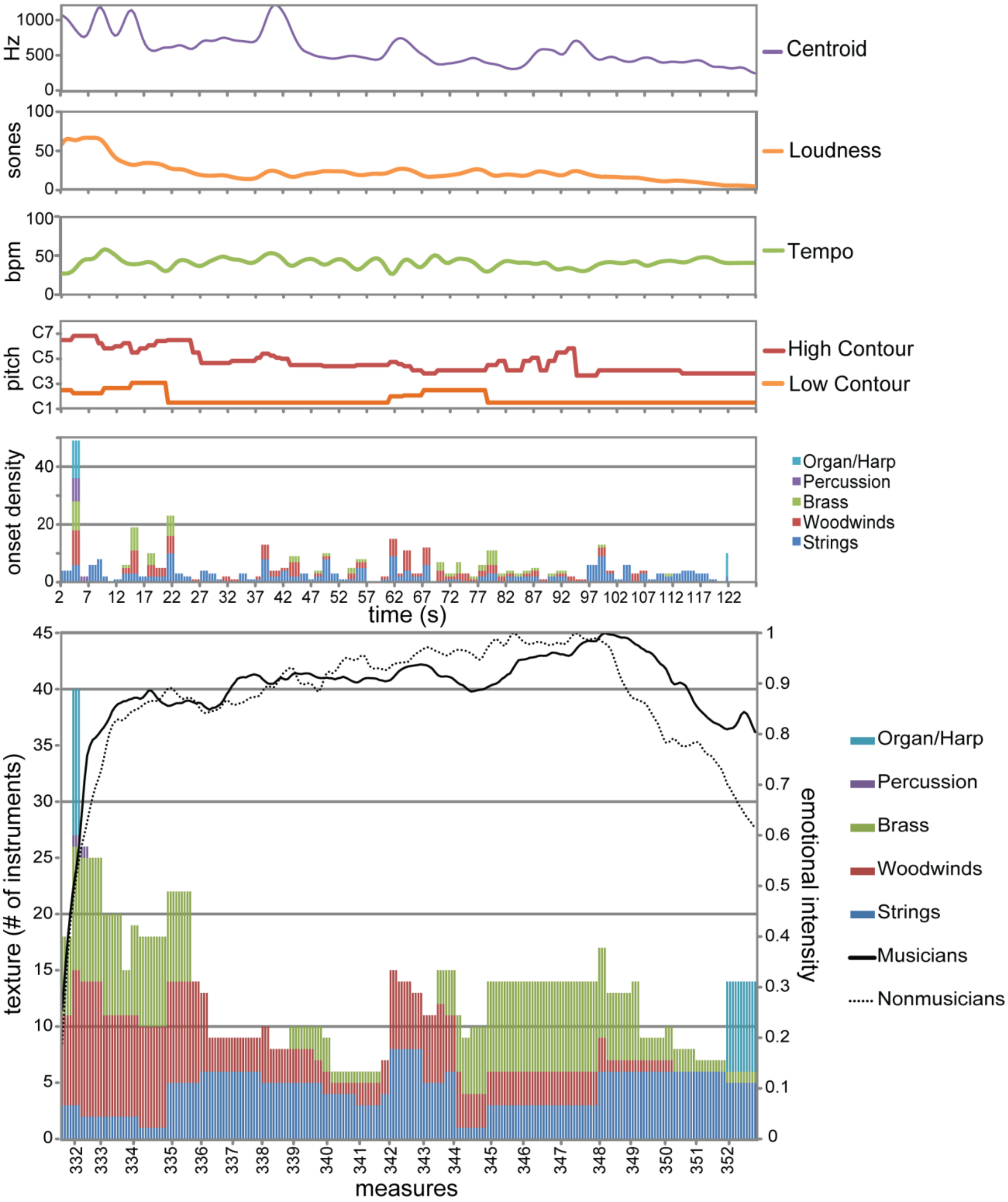
4. MUSSORGSKY/RAVEL, *PICTURES AT AN EXHIBITION,* "BYDLO," MM. 39-64



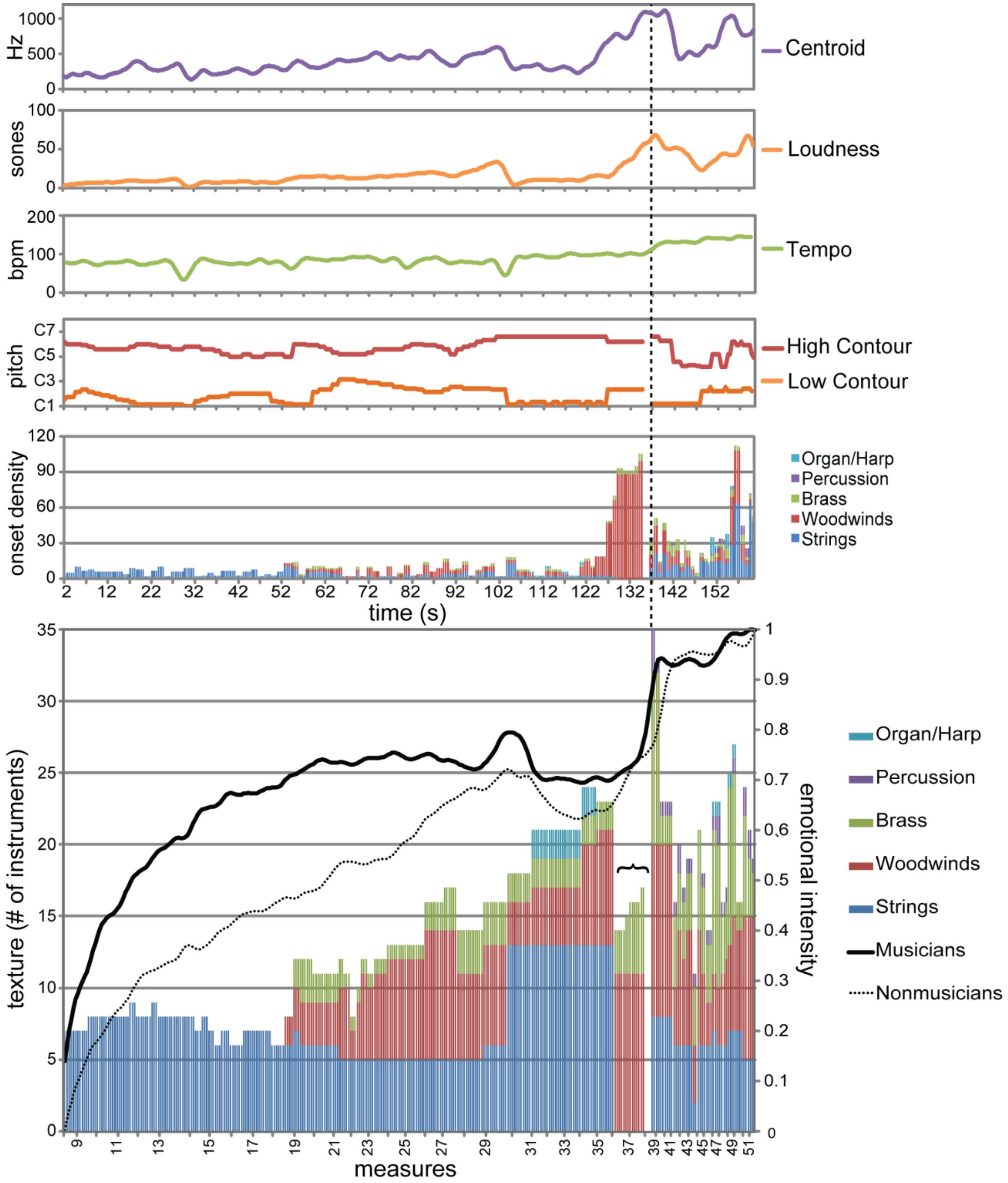
5. MAHLER, SYMPHONY 2, I, MM. 80-116



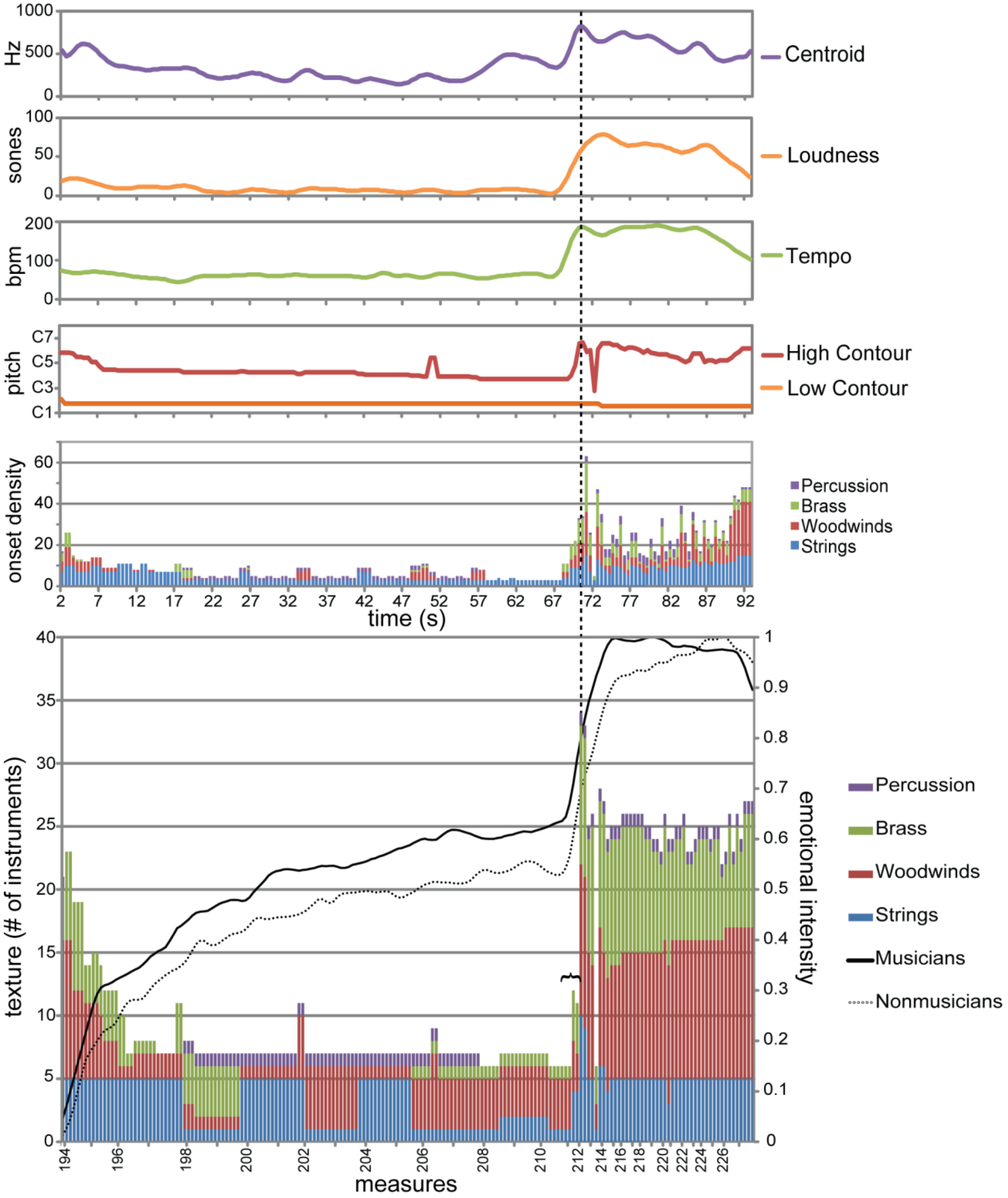
6. Strauss, *Ein Heldenleben*, III, mm. 331-353



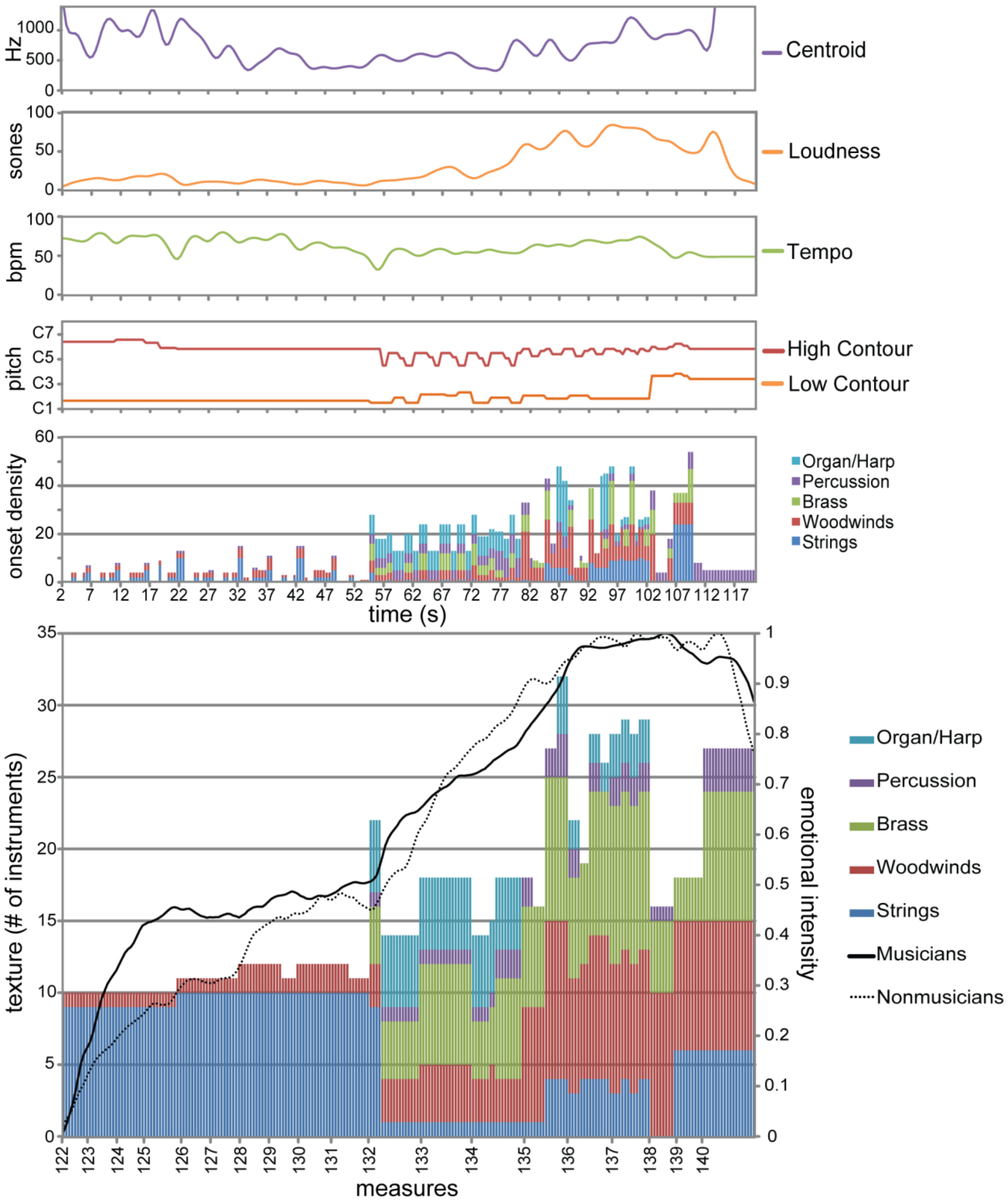
7. Vaughan Williams, *London Symphony*, I, mm. 8-53



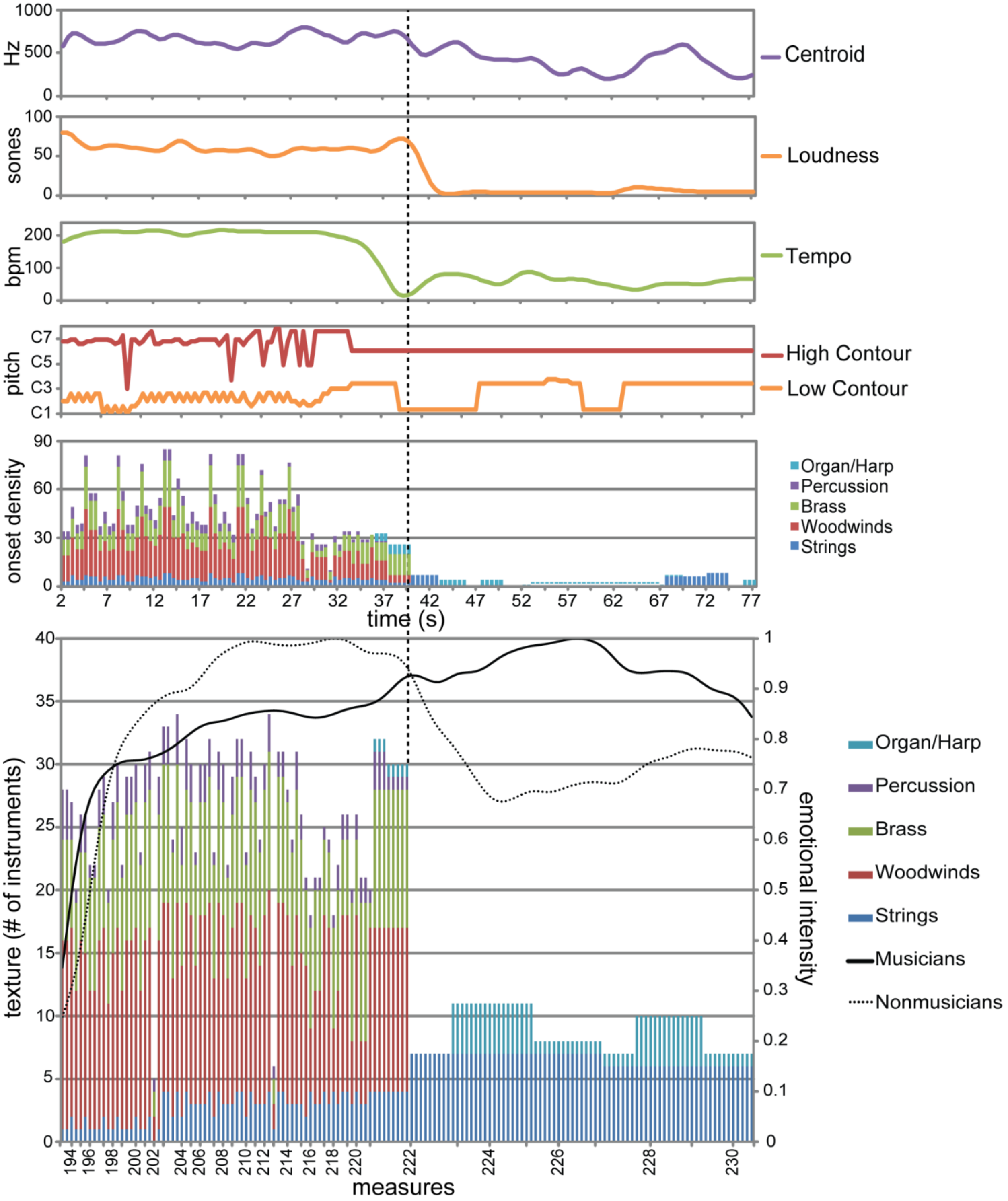
8. Strauss, *Tod und Verklärung*, II, mm. 360-395



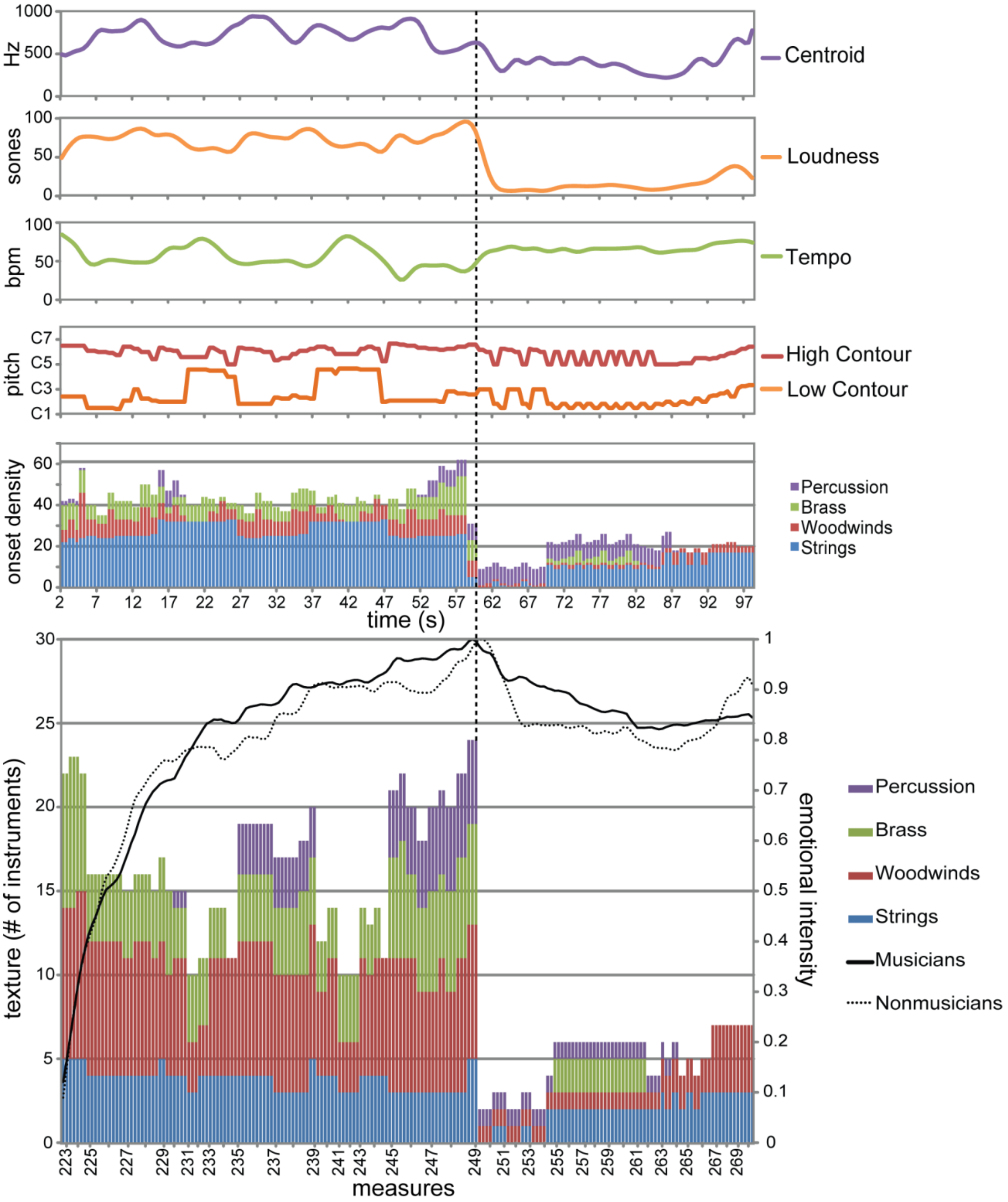
9. DEBUSSY, *LA MER*, I, MM. 122-141



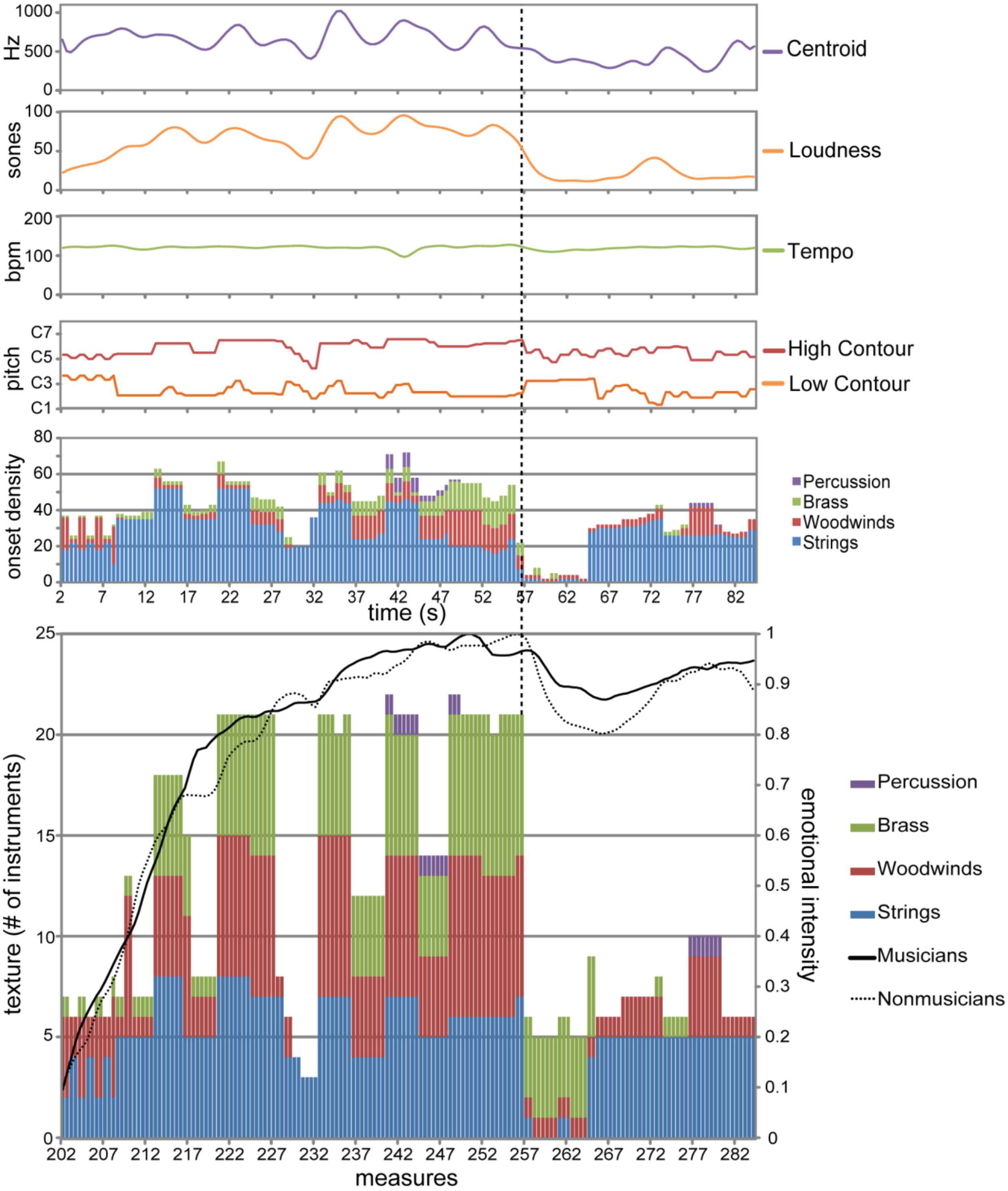
10. Holst, *The Planets*, “Uranus,” mm. 193-236



11. BRUCKNER, SYMPHONY 8, I, MM. 221-270



12. Dvořák, Symphony 9, I, mm. 200-286



APPENDIX B

BRUCKNER EXCERPT, RECOMPOSITIONS AND REORCHESTRATIONS

The following scores are introduced and explained in detail in Chapter 4. Appendix B1 contains the score for sudden reduction excerpt from Bruckner, Symphony 8, I, mm. 221-273. Appendices B2-B6 contain the recompositions and reorchestrations of this excerpt (mm. 248-268) as outlined and analyzed in Chapter 4. Thank you to Félix Frédéric Baril for completing the note entry in Finale and for the DOSim interpretation of these excerpts.

1. BRUCKNER, SYMPHONY 8, I, MM. 221-273


L
225
Fl.
Ob.
Cl. in Bb
Bsn.
Hn
Trp
Tromb.
Tuba
Timp.
Vl. I
Vl. II
Vla.
Vc.
Db.
fff
ff
a2
III
3


M
233
Fl.
Ob.
Cl. in Bb
Bsn.
Hn
Trp
Tromb.
Tuba
Vl. I
Vl. II
Vla.
Vc.
Db.
dim.
fff
ff
a2
3


241
Fl.
Ob.
Cl. in Bb
Bsn.
Hn
Trp
Tromb.
Tuba
Timp.
Vl. I
Vl. II
Vla.
Vc.
Db.
dim.
fff
ff
3


248
N
I II a2
III
III
Fl.
Ob.
Cl. in Bb
Bsn.
Hn
Trp
Tromb.
Tuba
Timp.
Vl. I
Vl. II
Vla.
Vc.
Db.
dim.
p
pp
3


256
Fl.
3
Trp
Timp.
256
Vl. I
pp
Vl. II
pp
Vla.
Vc.
Db.
8
O
263
Fl.
pp
Ob.
I
p
I
II
pp
Cl.
in Bb
I
p
a2
pp
Timp.
pp sempre
263
Vl. I
pp
Vl. II
pp
Vla.
pp
pp
Vc.
pp
Db.
8
pp


269
Fl.
cresc. molto
f
a2
Ob.
I
II
Cl.
in Bb
Bassoon
III
Bsn.
Hn
I
II
a2
III
IV
V
VI
Trp
Tromb.
Tuba
Vl. I
Vl. II
Vla.
Vc.
Db.

2. RECOMPOSITION OF BRUCKNER EXCERPT: EVADED VERSION


256
Fl.
Trp
Timp.
256
Vl. I
Vl. II
Vla.
Vc.
Db.
pp
pp


O
263
Fl.
Ob.
Cl. in Bb
Timp.
263
Vl. I
Vl. II
Vla.
Vc.
Db.
I
p
I
II
pp
a2
pp sempre
pp

3. RECOMPOSITION OF BRUCKNER EXCERPT: HARMONICALLY STABLE VERSION


256
Fl.
3
Trp
Timp.
256
Vl. I
pp
Vl. II
pp
Vla.
Vc.
Db.
8


O
263
Fl.
pp
Ob.
I
p
I
II
pp
a2
Cl.
in Bb
I
p
pp
Timp.
pp sempre
263
Vl. I
pp
Vl. II
pp
Vla.
pp
pp
Vc.
pp
Db.
8
pp

4. REORCHESTRATION OF BRUCKNER EXCERPT: STRING VERSION


256
Fl.
Trp
Timp.
Vl. I solo
3
256
Vl. I
Vl. II
pp
Vla.
Vc.
Db.


O
263
Fl.
pp
Ob.
I
p
I
II
pp
Cl. in Bb
I
p
a2
pp
Timp.
pp sempre
263
Vl. I
pp
pp
Vl. II
pp
Vla.
pp
pp
Vc.
pp
Db.
pp

5. REORCHESTRATION OF BRUCKNER EXCERPT: WOODWIND VERSION


256
Fl.
Ob.
Cl. in Bb
Bsn.
256
Hn
pp
pp
Trp
Timp.
256
Vl. I
pp
Vl. II
pp
Vla.
Vc.
Db.

6. REORCHESTRATION OF BRUCKNER EXCERPT: BRASS VERSION


256
Fl.
256
Hn
Trp
Tromb.
Tuba
Timp.
256
Vl. I
Vl. II
Vla.
Vc.
Db.
3
pp

APPENDIX C

BRIGHTENING AND DARKENING REORCHESTRATIONS

The following 12 visualizations are introduced and explained in detail in Chapters 4 and 5. Appendices C1-6 provide the scores for the expert reorchestrations of three excerpts as outlined in Chapter 4. Appendix C1 contains the dark version and C2 contains the bright version of Debussy, *La Mer*, I, mm. 121-141. The reorchestrations, score input, and DOSim interpretation were completed by Denys Bouliane.

Appendices C3 and C4 provide the dark and bright versions, respectively, of Vaughan Williams, *London Symphony*, I, mm. 8-53. The reorchestrations, score input, and DOSim interpretation were conducted by Félix Frédéric Baril.

Appendices C5 and C6 contain the dark and bright versions, respectively, of Holst, *The Planets*, “Uranus,” mm. 193-231. The reorchestrations and score input were completed by John Rea. The DOSim interpretation was completed by Baril.

1. DEBUSSY, *LA MER*, MM. 122-141: BRIGHT VERSION


2
Très lent ♪= 80
132
133
134
135
Fl. 1
Fl. 2
Picc.
Ob. 1
Ob. 2
E. H.
Cl. 1 (B♭)
Cl. 2 (B♭)
Bsn. 1
Bsn. 2
Bsn. 3
Hn. 1
Hn. 2
Hn. 3
Hn. 4
Tpt. 1 (C)
Tpt. 2 (C)
Tpt. 3 (C)
Tbn. 1
Tbn. 2
Tbn. 3
Tuba
Perc. 1
Perc. 2
Perc. 3
Perc. 4
Timp.
Harp 1
Harp 2
Vl. I Tutti
Vl. Ib
Vl. II Tutti
Vl. IIb
Vla. Tutti
Vc. Solo 1
Vc. Tutti
Db. Tutti
pp
ppp
p
mf
f
più f
mais très soutenu
cresc. molto
con sord
(small)
glissando
Tutti ord.
Tutti sul pont.
unis. ord.
sul pont


136
137
Retenu
138
139
a Tempo
140
141
Fl. 1
Fl. 2
Picc.
Ob. 1
Ob. 2
E. H.
Cl. 1 (B♭)
Cl. 2 (B♭)
Bsn. 1
Bsn. 2
Bsn. 3
Hn. 1
Hn. 2
Hn. 3
Hn. 4
Tpt. 1 (C)
Tpt. 2 (C)
Tpt. 3 (C)
Tbn. 1
Tbn. 2
Tbn. 3
Tuba
Perc. 1
Perc. 2
Perc. 3
Perc. 4
Timp.
Harp 1
Harp 2
Vl. I Tutti
Vl. II Tutti
Vla. Tutti
Vc. Tutti
Db. Tutti
f
più f
ff
sfz
p
ppp
fff
sffz
mp
(con sord)
sul pont.
(sul pont.)
pizz.
arrachez
8va

2. DEBUSSY, *LA MER*, MM. 122-141: DARK VERSION


2
Très lent ♪= 80
132
133
134
135
Fl. 1
Fl. 2
Picc.
Ob. 1
Ob. 2
E. H.
Cl. 1 (B♭)
Cl. 2 (B♭)
Bsn. 1
Bsn. 2
Bsn. 3
C. Bsn.
Hn. 1
Hn. 2
Hn. 3
Hn. 4
Tpt. 1 (C)
Tpt. 2 (C)
Tpt. 3 (C)
Tbn. 1
Tbn. 2
Tbn. 3
Tuba
Perc. 1
Perc. 2
Timp.
Harp 1
Harp 2
Vl. I Tutti
Vl. Ib
Vl. II Tutti
Vl. IIb
Vla. Tutti
Vc. Tutti
Db. Tutti
pp
mf
f
più f
p
ppp
mais très soutenu
cresc. molto
(large)
glissando
Tutti
unis.


136
137
Retenu
138
139
a Tempo
140
141
Fl. 1
Fl. 2
Picc.
Ob. 1
Ob. 2
E. H.
Cl. 1 (B♭)
Cl. 2 (B♭)
Bsn. 1
Bsn. 2
Bsn. 3
C. Bsn.
Hn. 1
Hn. 2
Hn. 3
Hn. 4
Tpt. 1 (C)
Tpt. 2 (C)
Tpt. 3 (C)
Tbn. 1
Tbn. 2
Tbn. 3
Tuba
Perc. 1
Perc. 2
Timp.
Harp 1
Harp 2
Vl. I Tutti
Vl. Ib
Vl. II Tutti
Vl. IIb
Vla. Tutti
Vc. Tutti
Db. Tutti
f
più f
ff
sfz
fff
p
mp
pizz.
arrachez

3. VAUGHAN WILLIAMS, LONDON SYMPHONY, I, MM. 8-53: BRIGHT VERSION


B
19
20
21
22
23
24
25
26
27
28
29
Flts.
Oboes
E. H.
Clts. in Bb.
Bass Cl.
Bsns.
C. Bsn.
Horns
Tpts. in F.
Corts. in B♭.
Trbs.
Tuba
Perc.
Timp.
Harp
Cel.
Vl. I
Vl. II
Vla.
Vc.
Db.
ppp
pp
mp
(p)
bouché
con sord.
8va
unis.
div.
mp cantabile


C
30
31
32
33
34
35
36
37
Flts.
Piccolo
ppp
cresc.
f
Oboes
E. H.
Clts. in Bb.
Bass Cl.
Bsns.
C. Bsn.
Horns
con sord.
senza sord.
mf
pp
Tpts. in F.
con sord.
Corts. in Bb.
senza sord.
Trbs.
Tuba
Perc.
Timp.
Harp
p
Cel.
Vl. I solo
8va
Vl. I
div.
Vl. II Solo
Vl. II
Vla.
Vc.
Db.


Allegro risoluto. molto pesante.
38
39
40
41
42
43
44
Flts.
Oboes
E. H.
Clts. in B♭.
Bass Cl.
Bsns.
C. Bsn.
Horns
Tpts. in F.
Corts. in B♭.
Trbs.
Tuba
cymbal (small)
Perc.
Timp.
Harp
Cel.
senza sord.
Vl. I
div.
Vl. II
Vla.
Vc.
Db.
unis.
sul pont.
pesante
fff
ff
mf
p
pp
3:2


D
45
46
47
48
49
50
51
52
53
Flts. 1. 2. 3.
Oboes 1. 2.
E. H.
Clts. in B♭ 1. 2.
Bass Cl.
Bsns. 1. 2.
C. Bsn.
Horns 1. 2. 3. 4.
Tpts. in F. 1. 2.
Corts. in B♭ 1. 2.
Trbs. 1. 2. 3.
Tuba
Perc.
Timp.
Harp
Cel.
Vl. I
Vl. II
Vla.
Vc.
Db.
pesante
con sord.
naturale
sul pont.
div.
8va

4. VAUGHAN WILLIAMS, LONDON SYMPHONY, I, MM. 8-53: DARK VERSION


B
19
20
21
22
23
24
25
26
27
28
29
Flts.
Alto
ppp
pp
Oboes
E. H.
Clts. in Bb.
mp
Bass Cl.
Bsns.
C. Bsn.
Horns
Tpts. in F.
Corts. in B♭.
Trbs.
(p)
Tuba
Perc.
Timp.
Harp
Vl. I
unis.
mp cantabile
Vl. II
Vla.
div.
Vc.
Db.


C
30
31
32
33
34
35
36
37
Flts.
Oboes
E. H.
Clts. in Bb.
Bass Cl.
Bsns.
C. Bsn.
Horns
Tpts. in F.
Corts. in B♭
Trbs.
Tuba
Perc.
Timp.
Harp
Vl. I
Vl. II
Vla.
Vc.
Db.
con sord.
senza sord.
div.
cresc.
ppp
pp
mf
f


Allegro risoluto. molto pesante.
38
39
40
41
42
43
44
Flts. 1. 2. 3.
Oboes 1. 2.
E. H.
Clts. in Bb. 1. 2.
Bass Cl.
Bsns. 1. 2.
C. Bsn.
Horns 1. 2. 3. 4.
Tpts. in F. 1. 2.
Corts. in B♭. 1. 2.
Trbs. 1. 2. 3.
Tuba
cymbal (large)
Perc.
Timp.
Harp
senza sord. div.
Vl. I
senza sord.
Vl. II
senza sord. div.
Vla.
unis.
div.
Vc.
Db.
pp pesante
fff
ff
f
mf
p
pp
3:2
8

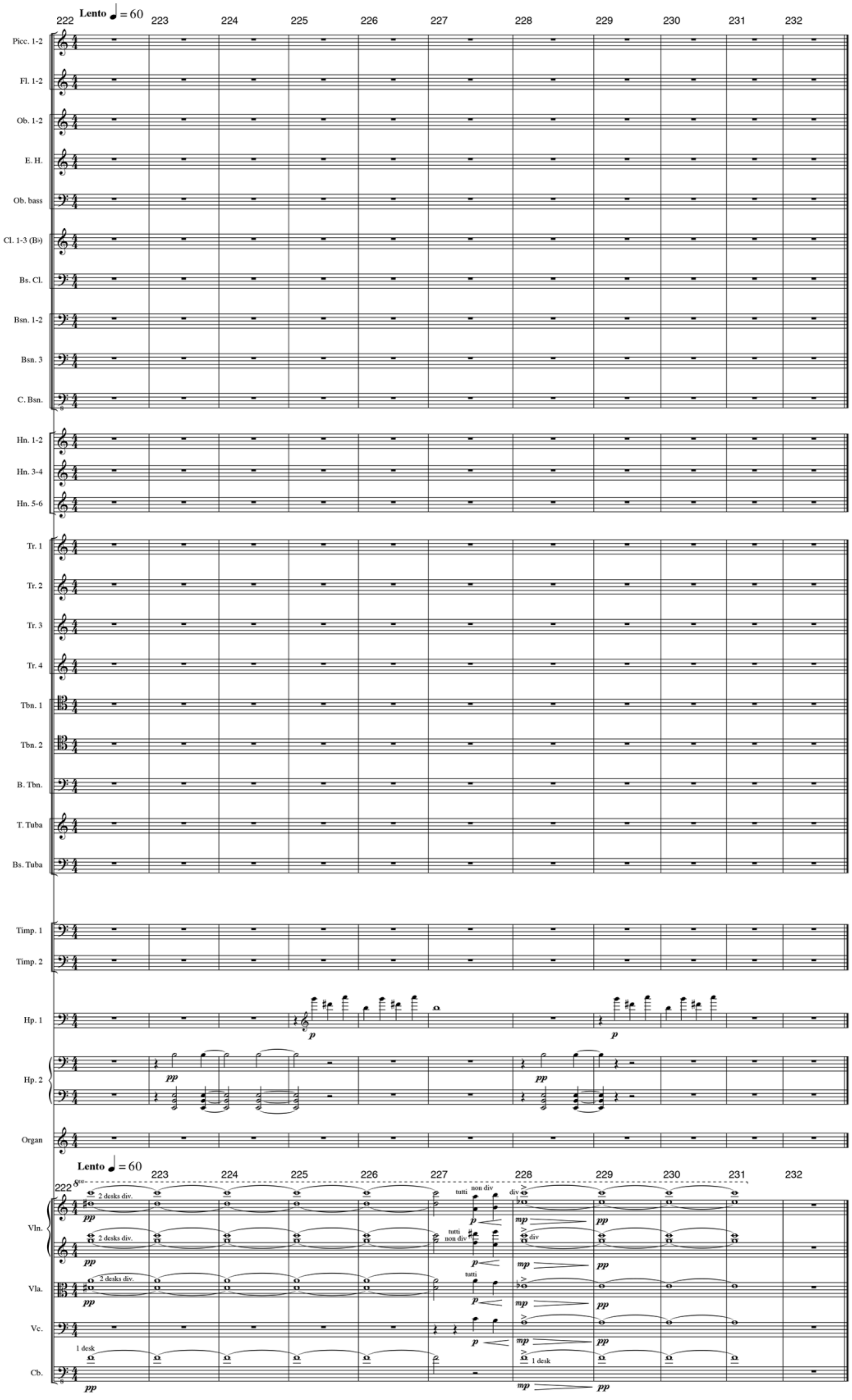

D
45
46
47
48
49
50
51
52
53
Flts. 1. 2. 3.
Piccolo
Oboes 1 2.
E. H.
Clts. in Bb. 1. 2.
Bass Cl.
Bsns. 1. 2.
C. Bsn.
Horns 1. 2. 3. 4.
Tpts. in F. 1. 2.
con sord.
Corts. in B♭. 1. 2.
Trbs. 1. 2. 3.
Tuba
Perc.
Timp.
Harp
Vl. I
Vl. II
Vla.
Vc.
Db.
naturale
div.
pesante
p pesante
pp pesante
ff
fff
pp
ppp
p
f
mf

5. HOLST, *THE PLANETS,* "URANUS," MM. 193-236: BRIGHT VERSION

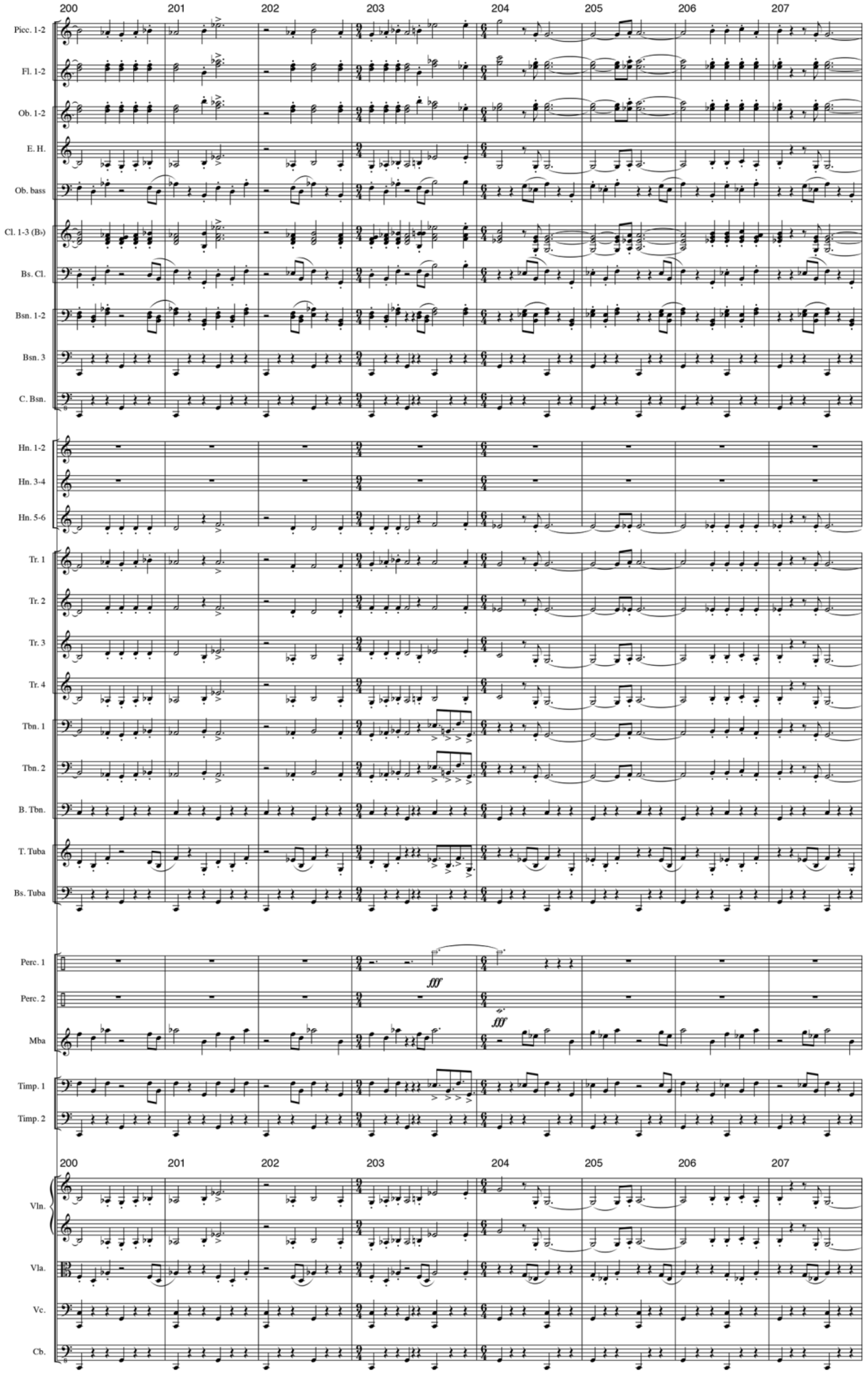

200
201
202
203
204
205
206
207
Picc. 1-2
Fl. 1-2
Ob. 1-2
E. H.
Ob. bass
Cl. 1-3 (B♭)
Bs. Cl.
Bsn. 1-2
Bsn. 3
C. Bsn.
Hn. 1-2
Hn. 3-4
Hn. 5-6
Tr. 1
Tr. 2
Tr. 3
Tr. 4
Tbn. 1
Tbn. 2
B. Tbn.
T. Tuba
Bs. Tuba
Perc. 1
fff
Perc. 2
fff
Xylo.
(8va)
8va
Timp. 1
Timp. 2
Vln.
(8va)
Vla.
Vc.
Cb.


208
209
210
211
212
213
214
Picc. 1-2
Fl. 1-2
Ob. 1-2
E. H.
Ob. bass
Cl. 1-3 (B♭)
Bs. Cl.
Bsn. 1-2
Bsn. 3
C. Bsn.
Hn. 1-2
Hn. 3-4
Hn. 5-6
Tr. 1
Tr. 2
Tr. 3
Tr. 4
Tbn. 1
Tbn. 2
B. Tbn.
T. Tuba
Bs. Tuba
Perc. 1
Perc. 2
Xylo.
Timp. 1
Timp. 2
Vln.
Vla.
Vc.
Cb.


215
216
217
218
219
220
221
Picc. 1-2
Fl. 1-2
Ob. 1-2
E. H.
Ob. bass
Cl. 1-3 (B♭)
Bs. Cl.
Bsn. 1-2
Bsn. 3
C. Bsn.
Hn. 1-2
Hn. 3-4
Hn. 5-6
Tr. 1
Tr. 2
Tr. 3
Tr. 4
Tbn. 1
Tbn. 2
B. Tbn.
T. Tuba
Bs. Tuba
Perc. 1
Perc. 2
Xylo.
Timp. 1
Timp. 2
Organ
Full organ
Vln.
Vla.
Vc.
Cb.
8va
ffff
f

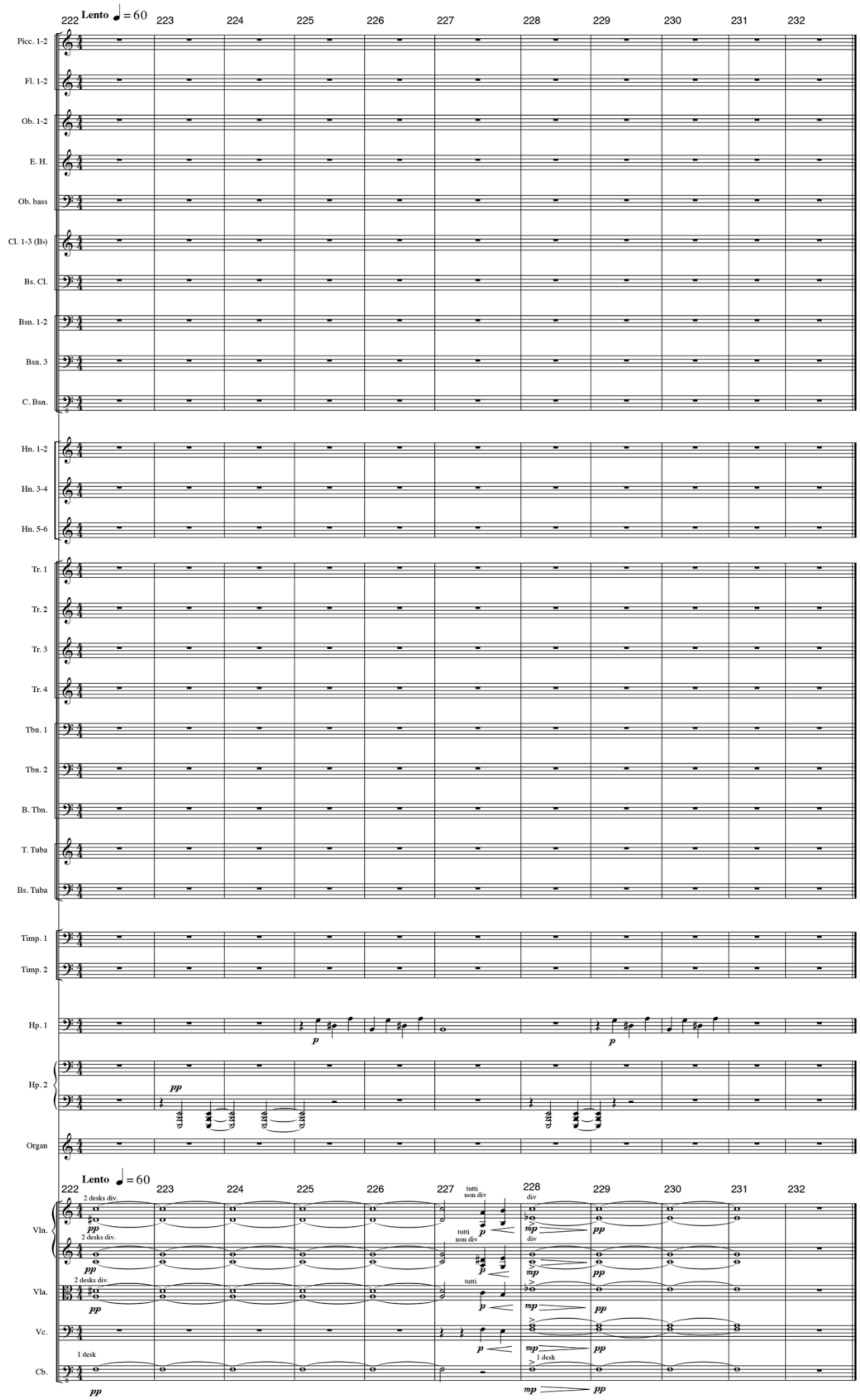

Lento ♩ = 60
222
223
224
225
226
227
228
229
230
231
232
Picc. 1-2
Fl. 1-2
Ob. 1-2
E. H.
Ob. bass
Cl. 1-3 (B♭)
Bs. Cl.
Bsn. 1-2
Bsn. 3
C. Bsn.
Hn. 1-2
Hn. 3-4
Hn. 5-6
Tr. 1
Tr. 2
Tr. 3
Tr. 4
Tbn. 1
Tbn. 2
B. Tbn.
T. Tuba
Bs. Tuba
Timp. 1
Timp. 2
Hp. 1
Hp. 2
Organ
Vln.
Vla.
Vc.
Cb.
p
pp
8va
2 desks div.
tutti
non div
div
1 desk
mp
pp

6. HOLST, *THE PLANETS,* "URANUS," MM. 193-236: DARK VERSION


200
201
202
203
204
205
206
207
Picc. 1-2
Fl. 1-2
Ob. 1-2
E. H.
Ob. bass
Cl. 1-3 (B♭)
Bs. Cl.
Bsn. 1-2
Bsn. 3
C. Bsn.
Hn. 1-2
Hn. 3-4
Hn. 5-6
Tr. 1
Tr. 2
Tr. 3
Tr. 4
Tbn. 1
Tbn. 2
B. Tbn.
T. Tuba
Bs. Tuba
Perc. 1
fff
Perc. 2
fff
Mba
Timp. 1
Timp. 2
200
201
202
203
204
205
206
207
Vln.
Vla.
Vc.
Cb.


208
209
210
211
212
213
214
Picc. 1-2
Fl. 1-2
Ob. 1-2
E. H.
Ob. bass
Cl. 1-3 (B♭)
Bs. Cl.
Bsn. 1-2
Bsn. 3
C. Bsn.
Hn. 1-2
Hn. 3-4
Hn. 5-6
Tr. 1
Tr. 2
Tr. 3
Tr. 4
Tbn. 1
Tbn. 2
B. Tbn.
T. Tuba
Bs. Tuba
Perc. 1
Perc. 2
Mba
Timp. 1
Timp. 2
Vln.
Vla.
Vc.
Cb.


215
216
217
218
219
220
221
Picc. 1-2
Fl. 1-2
Ob. 1-2
E. H.
Ob. bass
Cl. 1-3 (B♭)
Bs. Cl.
Bsn. 1-2
Bsn. 3
C. Bsn.
Hn. 1-2
Hn. 3-4
Hn. 5-6
Tr. 1
Tr. 2
Tr. 3
Tr. 4
Tbn. 1
Tbn. 2
B. Tbn.
T. Tuba
Bs. Tuba
Perc. 1
Perc. 2
Mba
Timp. 1
Timp. 2
Organ
Full organ
Vln.
Vla.
Vc.
Cb.
ffff
f


Lento ♩ = 60
222
223
224
225
226
227
228
229
230
231
232
Picc. 1-2
Fl. 1-2
Ob. 1-2
E. H.
Ob. bass
Cl. 1-3 (B♭)
Bs. Cl.
Bsn. 1-2
Bsn. 3
C. Bsn.
Hn. 1-2
Hn. 3-4
Hn. 5-6
Tr. 1
Tr. 2
Tr. 3
Tr. 4
Tbn. 1
Tbn. 2
B. Tbn.
T. Tuba
Bs. Tuba
Timp. 1
Timp. 2
Hp. 1
p
p
Hp. 2
pp
Organ
Lento ♩ = 60
Vln.
2 desks div.
pp
tutti
non div
p
div
mp
pp
2 desks div.
pp
tutti
non div
p
div
mp
pp
Vla.
2 desks div.
pp
tutti
p
mp
pp
Vc.
p
mp
pp
Cb.
1 desk
pp
1 desk
mp
pp