# Perceptual Processes in Orchestration

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Meghan Goodchild & Stephen McAdams, Schulich School of Music of McGill University

**Abstract**

The study of timbre and orchestration in music research is underdeveloped, with few theories to explain instrumental combinations and orchestral shaping. This chapter will outline connections between orchestration practices of the 19$^{th}$ and early 20$^{th}$ centuries and perceptual principles based on recent research in auditory scene analysis and timbre perception. Analyses of orchestration treatises and musical scores reveal an implicit understanding of auditory grouping principles by which many orchestral effects and techniques function. We will explore how concurrent grouping cues result in blended combinations of instruments, how sequential grouping into segregated melodies or stratified (foreground and background) layers is influenced by timbral (dis)similarities, and how segmental grouping cues create formal boundaries and expressive gestural shaping through changes in instrumental textures. This exploration will be framed within an examination of historical and contemporary discussion of orchestral effects and techniques.

**Introduction**

Orchestration and timbre are poorly understood and have been historically relegated to a secondary role in music scholarship, victims of the assumption that music's essential identity resides in its pitches and rhythms (Sandell 1995; Boulez 1987; Schoenberg 1994; Slawson 1985). Understanding of orchestration practices has been limited to a speculative, master-apprentice model of knowledge transmission lacking systematic research. Orchestration treatises and manuals mainly cover what is traditionally considered as "instrumentation," including practical considerations of instrument ranges, articulations, abilities and limitations, tone qualities, and other technical details. The topic of "orchestration," namely how to combine instruments in terms of balance, tone color, and clarity of musical lines, or how to use instrumental forces to shape musical form and expression, is less thoroughly addressed. Any kernels of what could be considered orchestration theory must be gleaned from passages providing general advice, based on tried-and-true conventions rather than underlying principles. Ultimately, the student of orchestration is advised to study short exemplars by the masters as recipes that are frequently not well introduced and often divorced from their original contexts.

As a result, understanding of orchestration practices is implicit, with expert knowledge of the art gained through experience. The number of factors contributing to orchestral sound is vast, with the role of expressive variation in performance, characteristics of the acoustic environment, recording techniques, and the interaction of these parameters posing additional significant challenges in developing such a theory. Many authors of orchestration treatises, both historical and modern, remark that orchestration can only be learned by careful, frequent listening and analysis over time. For example, Berlioz claims that the art of instrumentation "can no more be taught than the writing of beautiful melodies or beautiful chord progressions or original or powerful rhythmic patterns" (MacDonald [1855] 2002, 6). This belief persists, as Read (2004) asserts, "Every aspect, every facet, of orchestration is a part of creation and so defies the academic approach" (xii). Similarly, musicologist Rushton (2003) remarks "Attempts at formulating eternal laws for orchestration are no more successful than other aspects of musical creativity" (94).

However, there is evidence that certain orchestration conventions are based on underlying theory that has not been explicitly formalized. We argue that many orchestration practices, as revealed through analysis of orchestration treatises and scores, are related to auditory grouping principles. In terms of auditory scene analysis, the "job of perception … is to take the sensory input and to derive a useful representation of reality from it" (Bregman 1990, 3). Rather than hearing out individual frequency components, our brains evolved to perceive sound sources, and events produced by these sources result in auditory images—mental representations of sound entities that exhibit coherence in acoustic behavior (McAdams 1984). Orchestrators must harness this tacit understanding in order for listeners to comprehend complex musical relationships through instrumental scoring. Figure 1 outlines the grouping processes of auditory scene analysis and the resulting perceptual attributes related to music, and more specifically, to orchestral effects. First, concurrent grouping determines what components of sounds are grouped together into musical events, a process known as auditory fusion. This grouping process precedes the extraction of the perceptual attributes of these events, such as timbre, pitch, loudness, and spatial position. Next, sequential grouping governs whether these events are connected into single or multiple streams, on the basis of which perception of melodic contours and rhythmic patterns is determined. Finally, segmental grouping affects the "chunking" of streams into musical units, such as motives, phrases, and themes. In this context, auditory grouping processes are implicated in many orchestration practices, including the blending of instrument timbres due to concurrent grouping, the segregation of melodies based on timbral differences in sequential grouping, and call-response or echo-like exchanges through orchestral contrasts in segmental grouping.

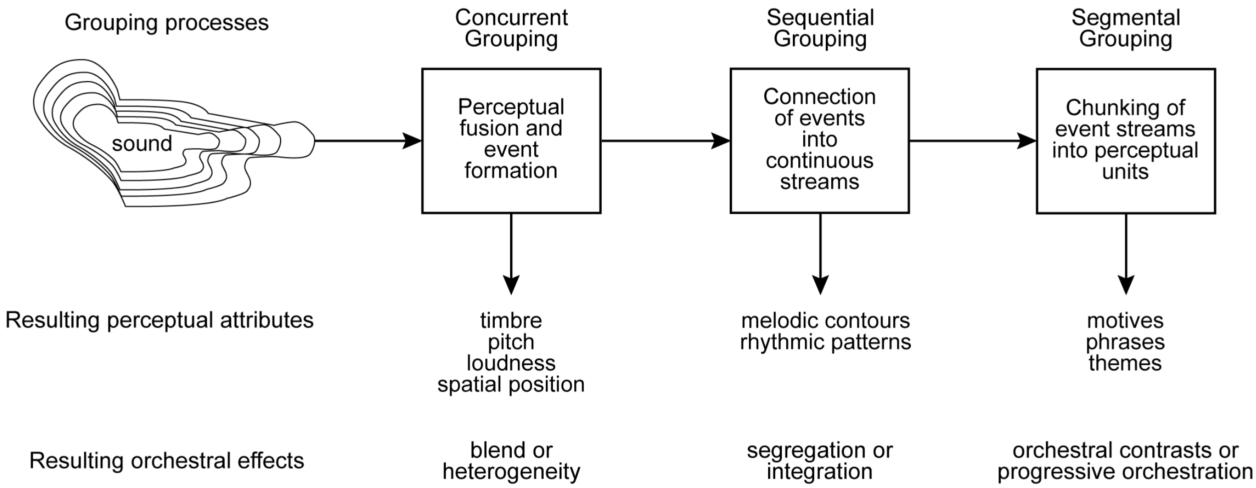



**Figure 1. Auditory grouping processes and the resulting perceptual attributes and orchestral effects**

Therefore, auditory grouping processes based on perceptual principles provide insight into implicit knowledge about orchestration. Bregman (1990) suggested that certain aspects of the art of orchestration that are not style-bound could be codified based on auditory scene analysis. In his vision, orchestration theory would delve into issues including:

> How can you make sounds fuse to create a single timbre? Which qualities of the individual sounds will contribute which aspects of this global timbre? How can multiple, simultaneous timbres be kept perceptually distinct from one another? What are the acoustic factors that are responsible for all these effects? Such a description would not be prescriptive, telling the composer what to do in the manner of traditional academic schools, but would simply say, "if you want this effect, do that, and here is the reason that it works." (458)

In this chapter, we will discuss implicit knowledge found in orchestration treatises and manuals through the lens of recent research in auditory scene analysis and timbre perception. We examine various ways in which these orchestration practices relate to perceptual principles and the implications for orchestration theory. Our aim is to reveal some of the mysteries behind this ostensibly arcane musical art.

## Blend and concurrent grouping

### *Orchestration manuals and treatises*

Orchestration at its core is the art and science of combining instruments. As evidenced in the title *Treatise on Instrumentation and Orchestration,* Berlioz differentiated between instrumentation—the study of instrumental technique—and orchestration—the study of the best methods for combining instruments (MacDonald [1855] 2002). Central to this understanding of orchestration is the notion of *appropriate* instrumental combinations (Mathews 2006). One of the common goals of combining instruments, and one of the primary topics of orchestration (Blatter 1997), is blending instrument timbres to create a uniform quality. This technique involves combining two or more instruments, most often at the unison or octave. Blends can occur over the course of a phrase by instrumental doubling at a constant intervallic distance. Orchestration manuals describe one possible result of blend in relation to altering the tone quality of a dominating instrument through the addition of one or more instruments. Many authors describe the result of this type of blend as *reinforcing* an instrumental part with another instrument (Piston 1955; Read 1979; Rimsky-Korsakov [1912] 1964). They often employ adjectives such as *thickening* or *softening* the timbre (Rimsky-Korsakov [1912] 1964; Kennan and Grantham 2002) or *strengthening* the timbre (Piston 1955) of the dominating instrument. Another result of blending is *mixing* or *uniting* timbres (Rimsky-Korsakov [1912] 1964; Piston 1955; Read 1979; Kennan and Grantham 2002), in which the combined instruments "blend as one, and neither predominates at any time" (Piston 1955, 155), thereby creating a new color or "new tone quality, if a homogeneous mixture is achieved" (Brant 2009, 18). Schnittke (2006) describes this phenomenon as timbral consonance: "a combination of related timbres that create a blended sonority difficult for the ear to analyze, in which the individual characteristics of instruments are fused into a single total color" (163).

Advice in orchestration treatises and manuals on the choice of instruments for blend is often prescriptive based on conventional practices. Common guidance for achieving blend is to consider the "affinity" of the instruments to be combined. Although not explicitly defined, affinity among instruments implies a perceived similarity. The implication is that any resemblance in their timbral characteristics, often in relation to their instrumental families, will assist in the goal of blending. For example, Rimsky-Korsakov ([1912] 1964) advises that woodwinds and strings blend well because they are "closely allied," whereas the strings and brass do not blend well, as "each is heard too distinctly" (33). He also instructs to avoid certain instrument combinations due to differences in their "peculiarities," (100) which suggests an implicit understanding of distinctive timbral features or traits. He notes:

> Uniting plucked strings and percussion with bowed instruments does not produce such a satisfactory blend, both qualities being heard independently. The combination of plucked strings with percussion alone, is excellent; the two blend perfectly, and the consequent increase in resonance yields an admirable effect. (34)

Here, Rimsky-Korsakov draws on the idea that the timbral characteristics related to articulation can contribute to achieving blend. Even in contemporary manuals, the notion of instrument affinities continues to guide predictions of blend. For example, Adler (2002) recommends "when doubling notes, find instruments that have an acoustic affinity for one another" (563). The horn, in particular, is commonly cited as a bridging instrument that links the brass section with the woodwind section due to its similar character (Rimsky-Korsakov [1912] 1964) and its ability to blend well with other instruments (Piston 1955; Adler 2002). The reverse situation of choosing instruments that are dissimilar to avoid blending is also noted. For example, Schnittke (2006) refers to "timbral dissonance" as the effect of distantly related instrument timbres retaining their own characteristics when combined. Similarly, Belkin (1988) distinguishes between combining similar families of sounds to create blend or unity and combining differentiated sounds to achieve variety and clarity of parts.

As a succinct summary of orchestration manuals, Sandell (1995) identified three sonic goals of orchestration for concurrently combining instruments. The main distinction involves whether or not the aim is for the instruments to blend. One objective is *heterogeneity*, the absence of blend, in which the instrument sounds are separately identifiable and emphasize the independence of the instrument timbres. He also proposed two types of blend: augmentation and emergence. The former involves a dominant instrument that is embellished by a subordinate instrument or group of subordinate instruments, thereby adding a color or quality to the dominant instrument. The latter involves synthesizing a new instrument timbre that is identified as none of its constituent timbres.

*Auditory scene analysis and blend studies*

Through the lens of auditory scene analysis, timbre is a perceptual attribute that arises from concurrent grouping processes (see Figure 1). Therefore, blend as an orchestral effect is the result of the perceptual fusion of different instrument sounds, providing the illusion of originating from a single sound source. A listener's perception of a blended instrument timbre depends on the acoustical components that are grouped together by the auditory system and that collectively give rise to emergent acoustical properties. This grouping is influenced by certain cues from the environment, including whether the acoustic components begin synchronously (onset synchrony), whether they are related by a common period (harmonicity), and whether there is coherent frequency and amplitude behavior (McAdams 1984). The coherent behavior cues are rooted in the Gestalt principle of "common fate": sounds that change in a similar manner are likely to have originated from the same source (Bregman 1990). Deviations from synchrony, harmonicity and parallel change in pitch and dynamics are likely to signal to the brain that there are two or more sources present in the environment and to provide the necessary information to organize and group their respective frequency components separately. Thus, instrument combinations are more likely to be perceived as blended if they adhere to these principles. Orchestration manuals advise such a procedure in terms of strictly doubling a melodic line, most often at the unison or octave. A classic example of the combined use of these cues is found in Ravel's *Boléro* in which he builds complex timbres in "virtual sound sources" by stacking instruments in a harmonic series (fundamental pitch, octave, twelfth, double octave, etc.) and having them play in synchrony and in perfect parallelism in terms of both pitch and dynamics.

The choice of instruments also has implications for blend related to the combined timbral properties. But first let us consider briefly how such properties are determined experimentally. The multidimensional nature of timbre has been researched within the field of psychology related to music perception. To understand the complex perceptual dimensions of timbre, one major approach has been through multidimensional scaling (MDS): listeners' ratings of the dissimilarity of instrument pairs are compared to create a matrix that is fitted to a distance model (McAdams 1993). The resulting representation is known as a "timbre space," which reveals the perceptual similarity of instrument timbres in terms of distances along a certain number of dimensions, usually two or three (McAdams et al. 1995; Grey 1977). The perceptual dimensions correlate most often with acoustical descriptors that are *temporal*, such as attack time (the time required to reach maximum amplitude), *spectral*, such as spectral centroid (the center of gravity of the relative weights of the frequencies present, related to timbral brightness), or *spectrotemporal*, such as spectral flux (the irregularity of the spectrum over time) (McAdams 2013). The combination of these features can also distinguish different instrument families and modes of excitation (plucked vs. bowed, for example) (Giordano and McAdams 2010).

Recent research has attempted to link timbre perception research with aspects of orchestration practice. Sandell (1995) investigated the relationship between perceptual judgments of blended instrument pairs and the acoustical properties of the instrument sounds, which were computer-synthesized tones of string, woodwind, and brass instruments, equalized for loudness, pitch, and duration. He found that brighter instruments (instruments with a higher spectral centroid) 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 temporal attributes, resulted in higher blend ratings. In a similar study, spectral and temporal similarity contributed to higher blend ratings for wind instrument combinations (Kendall and Carterette 1993). In combining impulsive and sustained sounds, blend ratings are higher for sounds with lower spectral centroids and slower attacks, and the timbre resulting from the blend is primarily determined by the attack of the impulsive sound and the spectral characteristics of the sustained sound (Tardieu and McAdams 2012).

In addition to global descriptors, such as spectral centroid, research has also been conducted on the role of local descriptors of format structure (prominent spectral maxima, invariant to pitch change) on wind and brass instrument blends (Lembke and McAdams 2015; Reuter 2003). The relative location and prominence of the main formants were found to affect the perception of blend, such that the presence of subordinate instruments' formants above that of the dominant instrument results in decreased blend.

The results of perceptual studies have implications for orchestration theory. Acoustical properties of instrument timbres can be used to understand instrument blend pairings found in orchestration manuals and to predict future pairs. Traditional lists of good and bad instrumental combinations can be supplemented with temporal, spectral, and spectrotemporal acoustical characteristics of instrument timbres. As a result, vague notions of instrumental affinity can be updated by explicit descriptions of timbral features that contribute to perceptual blend ratings. Of particular importance is the inclusion of attack characteristics of instruments and their articulations to aid in achieving onset synchronicity, as well as spectral centroid calculations at various pitches to assist with selecting instruments that are similar in their brightness. Instrumental formant structure (or spectral shape, more generally) and the contribution of performers' intensions (Lembke, Levine, and McAdams 2017) would also provide useful guidance for orchestrators. Future studies also need to investigate how to predict which timbres are likely to be dominant or remain identifiable in a blend.

Recomposition, a music-theoretical method to examine alternative musical possibilities, could be used more systematically than the traditional informal approach to provide a pedagogical tool for studying orchestration choices. For example, Adler (2002) discusses the "mysterious color" (233) of the unison doubling of oboe and clarinet found in the first theme of the first movement of Schubert's Eighth Symphony, a pairing which many orchestration manuals discourage students from employing due to performance difficulties of balance and intonation (see Example 1). As summarized in Table 1, he imagines several recompositions as alternative scorings—flute and oboe, flute and clarinet, and the aforementioned instruments and bassoon—with descriptions of the effect of the resulting blends. In future work, systematic recompositions or reorchestrations of instrument combinations could be complemented by acoustical analyses of instrument blends. The results of perceptual listening experiments in which listeners rate the degree of blend on a continuum could be used to provide further evidence for why certain combinations work in certain contexts.


**Example 1. Blend between oboe and clarinet (annotated with grey box) in Schubert, Symphony 8, I, mm. 12-17.**

**Table 1. Possible instrument combination choices and descriptions of resulting blend effects for the opening theme of Schubert's Symphony 8, I (adapted from Adler 2002)**

| Instrument combinations | Description | Page |
|---|---|---|
| Oboe and clarinet (unison) | By doubling the oboe with the clarinet, he created a passage with a mysterious color. Every live performance of this passage will sound slightly different; the instruments, the players, and the acoustics of the hall will all play a part. | 233 |
| Flute and oboe (unison) | The oboe, in a more advantageous register, will stand out, but the flute will neutralize the nasal quality of the oboe and give the passage a rounder, richer sound. | 233 |
| Flute and clarinet (unison) | If we combine flute with clarinet, we eliminate the bite of the oboe sound, but the clarinet stands out almost exclusively: the flute is in a nonbrilliant register, contributing little more than a thickening of the resulting tone. | 233 |
| Oboe and bassoon (octave) | The bassoon, which cannot play this melody in the same range as the flute, oboe, or clarinet, could instead be doubled with any one of these instruments at the octave. Any of these combinations would be quite sonorous | 234 |
| Flute, clarinet, and bassoon (3 octave spread) | | |

**Segregation, stratification, and sequential grouping**

*Orchestration manuals and treatises*

In addition to combining instruments to blend their timbres, orchestration treatises also outline the ways in which instruments can be scored as part of the horizontally woven musical fabric. One major topic involves methods to clearly project individual lines of counterpoint. Several elements—proper instrument register, registral (pitch) separation, and rhythmic diversity—are frequently cited in historical and contemporary orchestration manuals to ensure separation of the individual parts. For example, Adler (2002) outlines several steps to differentiate the contrapuntal voices in terms of clarity and balance when scoring for a homogeneous section of instruments, such as the string family:

> When contrapuntal passages are to be scored for strings alone, two major points to consider are clarity and balance. These can best be achieved by:
> 1. placing the most important melody in the best possible register of an instrument; 2. thinning the counterpoint to let the main theme break through;
> 3. registrally separating theme and countertheme (one high, one low, or vice versa); 4. making the countertheme sufficiently different rhythmically from the primary theme that they don't interfere with one another when the two are stated together. (135)

It is important to note that timbre changes with register to some extent for all instruments, so in some sense register-based principles involve both pitch and timbre considerations. However, there is less consensus regarding the specific role of differences in instrumental timbres on scoring counterpoint. For several authors, the most effective approach involves separating contrapuntal parts by timbral differentiation, that is, by scoring the individual lines with different instruments or blended instrument groupings. In discussing Berlioz's *Roman Carnival Overture*, Adler (2002) notes, "The effectiveness of the canon in this excerpt is due as much to color contrasts as to registral differences, which separate the various statements of the canonic subject" (392). Indeed, Adler considers that the use of timbral differentiation assists the listener in understanding the polyphonic structure of the passage. In discussing the fourth movement of Mozart's "Jupiter" Symphony, he observes, "Once the web of counterpoint becomes truly involved Mozart keeps an established color combination long enough to play the entire theme intact so that the listener is not overburdened with the task of picking out the main musical ideas" (583). Schnittke (2006) also suggests that timbral dissimilarity aids in projecting contrapuntal lines. Building on his concept of timbral dissonance (i.e., distantly related timbres that retain their individual characteristics when combined), he describes "timbral polyphony" as a "consistent prolonged dissonance of timbres [which] serves to intensify the prolongation of melodic polyphony" (163).

For other authors, the contrapuntal structure itself dictates how to score the individual parts. Brant (2009) differentiates between two types of counterpoint. For counterpoint in which the parts are related by common rhythmic and intervallic profiles, such as in imitative counterpoint, scoring with one timbral quality or a related group of timbres is appropriate to highlight the relationships among the parts. For "contrasted counterpoint," which features rhythmic and intervallic differences among the parts, Brant recommends assigning different timbres to emphasize the distinction of each part. He adds, "Depending on the amount of contrast desired, the choice of tone-qualities may vary from different timbres of the same class to highly contrasted tone-qualities which have little in common" (28). Kennan and Grantham (2002) acknowledge the advantage of utilizing the vast orchestral palette to clarify the polyphonic musical structure, but they advise that the orchestrator must consider the relative weights of the instrumental colors to balance each line:

> One of the main objectives in scoring linear music is to bring out the individual voices clearly. Here the orchestra has a certain advantage over the piano: whereas the piano has only one color to offer, the orchestra has many, and by allotting a different color to each voice we can give the lines a clarity and independence—a kind of three-dimensional feeling—that is impossible on the piano. For example, if three voices are involved, we might give one to oboe, one to clarinet, and one to bassoon. But it is not always necessary to use sharply contrasting colors. The three voices might be given instead to violins, violas, and cellos, respectively, in which case the differences in timbre, although less decided, would still afford a small color contrast between the parts. Although it is possible to use instruments of different sections on the various parts, one must be careful to choose instruments that can be made to balance properly. It is also possible to contrast one composite (mixed) color with another composite color or with a pure color. (292-293)

In addition to scoring contrapuntal parts, orchestration treatises and manuals also discuss orchestral layering. This concept of stratification involves two or more layers of musical material, separated into more and less prominent strands. At minimum, stratification creates the impression of foreground and background material, but can also comprise one or more middleground layers. Composers frequently employ stratification in relation to the homophonic style of writing, often expressed in terms of melody and accompaniment.

Orchestration manuals outline the importance of highlighting the melody in contrast to accompanimental material. For example, Rimsky-Korsakov ([1912] 1964) advises that melody and accompaniment can be differentiated through contrasts in dynamics as well as instrumentation:

> [M]elody should always stand out in relief from the accompaniment. This may be done by artificial or natural means; artificially, when the question of tone quality does not come into consideration, and the melody is detached by means of strongly accentuated dynamic shades; naturally, by selection and contrast of timbres, strengthening of resonance by doubling, tripling, etc., or crossing of parts (violon-cellos above the violas and violins, clarinets or oboes above the flutes, bassoons above the clarinets, etc.). (36)

Many orchestration manuals discuss the use of instrumental colors to differentiate among foreground and background layers. Blatter (1997) notes that more prominent lines are generally given more colorful treatment, while subordinate lines are less vivid. He describes it thus: "Often the use of rather somber and pallid colors can serve as a perfect and desirable preparation or backdrop for more brilliant and exciting hues" (330). He notes that the use of "colorful" is used in a relative sense depending on the context, such that the oboe, for example, would be perceived as colorful in relation to a string section but not a double reed choir. Similarly, Kennan and Grantham's (2002) advice for orchestrating homophonic music is to emphasize the melodic line against the subordinate background through differences in instrumental coloring: "by giving the melody to one color, the background to another" (209). In one example, Kennan and Grantham discuss various options including a solo woodwind melody and background strings, a violin melody and background horns, or a violin melody and a background of muted strings. They also discuss the technique for highlighting the melody using blended instruments to add richness and expressivity (e.g., unison blend of horn and cello for gentle, *cantabile* melodies). However, they warn against the overuse of blended doublings, which can become "uninteresting and [tend] to make a score sound opaque and nondescript. Pure colors are needed for sparkle and transparency" (213). Similarly, Blatter (1997) cautions against overuse of blended instruments in creating a powerful and effective foreground: "But much as the mixing of many colored lights will produce a gray-white light, the orchestral unison may more rapidly lose its ability to sound fresh than will the sound of a single solo instrument" (330).

Many orchestration manuals advise against writing stratified layers within the same pitch register when scoring for instruments with a similar color. However, this guideline is lifted when incorporating timbral differences among the layers. For example, Adler (2002) explains the effective layering effect (see Example 2) in the opening of the third movement of Brahms's Third Symphony:

> 1. The foreground line is in the best register of the instrument to which it was assigned. 2. The background figures are in the palest or most nondescript registers of the instruments to which these were given, and the double-bass pizzicatos lessen the aural impact of the bass line. (123)

Here, Adler references the pale quality of the instrumental timbres as well as different attack characteristics that diminish the salience of the background layer as a neutral plane upon which the foreground can be contrasted, even within a similar pitch range.


**Example 2. Foreground layer in the cello (annotated with grey box) against background layer in Brahms's Symphony 3, III, mm. 1-5.**

Similarly, Brant (2009) describes how to contrast layers when superimposing textures in terms of rhythmic profile, instrumental families (e.g., string section vs. woodwinds), and articulation. Brant describes varying the articulation as a "timbral ingredient," (218) such as *pizzicato* compared to sustain techniques, which provides differentiation among layers.

Drawing on Koechlin's (1959) *Traité de l'orchestration*, Belkin (1988) outlines how composers can distinguish foreground from background textures by assigning different levels of perceptual prominence. Foreground layers are striking, strongly defined, and richly varied, to set in high relief the background layers. The layering creates a sense of depth, often through differences in instrumental timbre, rhythmic profile, register, spectral composition, and gestural shape.

*Auditory scene analysis and segregation studies*

Orchestration practices of segregating contrapuntal parts and stratifying layers by timbral differentiation can be understood in relation to sequential grouping processes (see Figure 1). Following event formation, auditory stream formation involves the perceptual connection of events into an auditory stream, a mental representation of continuous sound activity. Sequential grouping processes organize successive events into a single stream or multiple streams based on specific cues, which are closely related to Gestalt principles of proximity (i.e., closeness in time) and similarity (i.e., acoustic connection) (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 promote 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 within which events are similar.

Several studies have studied the factors involved with auditory stream segregation related to frequency separation and the rate of presentation of successive tones (Van Noorden 1975; Miller and Heise 1950). A sequence of tones that alternates between two pitches can be perceived by listeners as a single coherent stream (a trill) or two distinct streams (as separate pulsing lines) depending on the degree of perceptual difference between successive sounds (Moore and Gockel 2002). Van Noorden (1975) found that two different boundaries can be measured depending on listener focus and attention. When listeners attempt to perceive a single stream, the point at which segregation occurs depends on frequency separation and tempo; this temporal coherence boundary occurs when the pitch separation is large and the tempo is fast. When listeners attempt to perceive two streams, integration into a single stream occurs when the pitch separation is very small, independent of tempo (fission boundary). Between these two boundaries is an ambiguous region that depends on musical context and the listeners' attention and focus. Composers have been exploiting this phenomenon for centuries to create the effect of two simultaneous melodic lines played by a single instrument (Huron 2016). This type of pseudo-polyphony (also known as a compound melody or bi-linear melody) is achieved with a monophonic line by large pitch jumps at a fast tempo, often found in Baroque music, particularly in Bach's cello suites.

Perceptual studies have shown that auditory stream segregation is strongly influenced by timbral differences (McAdams and Bregman 1979; Gregory 1994). In Wessel's (1979) demonstration, an ascending triplet pattern is heard when a single instrument plays the melody, whereas two descending triplet patterns at half tempo are heard when every other pitch is replaced by a second instrument with a sufficient timbral difference (see Figure 2). Therefore, different orchestrations of the same pitch sequence can affect the perception of melody and rhythm.

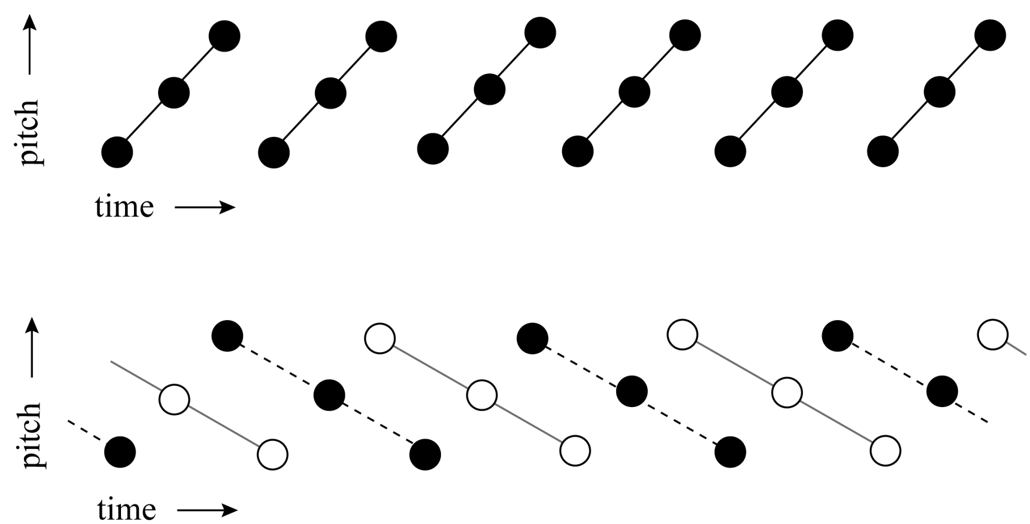



**Figure 2. Two versions of a melody created by David Wessel with one instrument (top) or two alternating instruments (bottom), which cause the sequence to reorganize into two auditory streams**

Iverson (1995) measured the perceived degree of segregation for tone sequences that alternate between two instruments. The extent to which the sequence segregated into two streams was correlated with the perceived timbral dissimilarity (as modeled by multidimensional scaling), with listeners segregating pitches with greater timbral dissimilarity. The acoustical attributes involved were both static (spectral centroid) and dynamic (attack duration) in nature. Building upon this research, 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 was near chance when the target and distractor were played by the same instrument in the same pitch register. However, their accuracy increased as a function of the timbral dissimilarity between the target and distractor instruments, as modeled by MDS (McAdams et al. 1995).

Timbral differentiation of individual contrapuntal parts also has implications for the perception of musical tension. In Paraskeva and McAdams's (1997) study, listeners rated the perceived degree of completion (the inverse of tension) after a series of musical segments for both piano and orchestral versions of a tonal work (Bach's "Ricercar a 6" from *The Musical Offering,* orchestrated by Webern) and an atonal work (Webern's *Six Pieces for Orchestra*, op. 6, no. 1, for which the piano version was a direct transcription). They found that when there were differences in the completion ratings, the orchestral versions were consistently rated as less tense than the piano versions. To explain these results, Paraskeva and McAdams posited that the timbral attribute of roughness, caused by sensory dissonance from concurrent grouping processes, would differ between the piano and orchestral versions. Due to the homogeneous instrumental timbre and synchronous attacks, the piano versions may have led to greater concurrent grouping of vertical intervals, resulting in greater sensory dissonance. In the orchestral versions, however, the individual parts played by different instruments (with timbral differentiation and attack differences) would have a greater tendency to segregate into separate streams. As a result, there would be a decreased fusion of vertical sonorities and resulting sensory dissonance, thereby reducing the perception of musical tension. For more information, McAdams (2015) provides a detailed analysis of the role of timbre in tension perception and Wright and Bregman (1987) illustrate several ways in which concurrent and sequential grouping processes interact and affect the perception of dissonance and tension.

These studies on the role of timbre on stream segregation have important implications for understanding orchestration practice, as the choice of instrumentation may promote or prevent segregation of melodies. The results of this sequential streaming in turn will affect the perception of melody and rhythm. Depending on the aims of the composer or orchestrator, segregation can be encouraged by weakening the blend or auditory fusion among notes of different contrapuntal parts, drawing on principles of both concurrent and sequential grouping. Orchestration manuals could more explicitly outline how to score the instrumentation to ensure independence of contrapuntal parts, which would involve rhythmic and melodic differentiation, avoidance of harmonicity, and spectral discontinuity of pitch and timbre between the parts. The inclusion of the results of acoustical and perceptual tests related to timbral dissimilarity would also assist in predicting which instruments may be best suited to contrast one another in a contrapuntal context.

Given the effectiveness of timbral differentiation on the segregation of contrapuntal parts, Huron (2016) remarks how surprising it is that composers often adopt more homogeneous instrument groupings in polyphonic works, such as the extensive repertoire for string quartet, brass ensembles, vocal groups, and solo keyboards. He hypothesizes that this choice may be related to the goal of balance among the parts since heterogeneous ensembles bring difficulties in relation to differences among the instruments in terms of their acoustical power and their ability to capture the listener's attention. For this reason, he suggests that timbral differentiation is the main device used to distinguish foreground from background layers. However, we predict that the assignment of instruments to foreground or background layers depends on timbral salience; more salient timbres would draw the listener's attention to that particular instrument or instrumental blend, which would then occupy the foreground.

This distinction between balanced counterpoint and stratified layers underlies the dialectic of French and German orchestration brought to the fore in the late nineteenth century and early twentieth century. French orchestration is characterized by homophonic textures in which the layers are set in relief by different tone colors, whereas German orchestration is characterized by contrapuntal textures in which blended timbres add weight and volume to individual lines (Mathews 2006). Following the German tradition, Schoenberg criticized the use of colorful instrumental individuality, advocating for a smaller number of orchestral colors within a more homogeneous and evenly balanced ensemble (DeThorne 2014). The divide centers on the manner in which instrumentation is used to clarify musical ideas: *colorful plasticity* uses timbral colors to distinguish among the individual parts, whereas *equalized transparency* strives to subtly distinguish the parts while maintaining a cohesive sound. Auditory scene analysis research could open new avenues for investigating this distinction, particularly the degree to which listeners are able to follow musical themes and motivic connections within original versions and orchestral arrangements by Schoenberg and others.

To our knowledge, no research has been conducted on the perception of stratified layers. Future research will need to test whether timbral similarity within layers and timbral differences among layers contributes to their perceptual separation. In preliminary research, we used data mining techniques of frequent pattern analysis on annotations of stratification excerpts within a corpus of orchestral scores (Goodchild and McAdams 2016). The results indicate that members of the string family are most often scored in a background role, whereas woodwinds are more often scored in a foreground role, likely related to the unique, and perhaps more salient, timbral characteristics of these families. Further perceptual experimentation is also needed to investigate the timbral features that promote the prominence or salience of foreground layers compared to background ones.

## Orchestral contrasts, progressive orchestration, and segmental grouping

### *Orchestration manuals and treatises*

In addition to considerations of combining instruments to blend and to create musical strands or layers, orchestration manuals offer some advice regarding how instrumental scoring can be used to shape the musical structure, referencing gradual and sudden rates of change. Along these lines, Adler (2002) describes methods to utilize timbral similarities and differences among the string, woodwind and brass families: distinct contrasts feature the stark alternation of the instrumental families to outline musical units, whereas a gradual progression promotes a sense of continuity. For example, Adler (2002) states:

> One obvious use of the wind section is to provide contrasting color to the string section. This can be done in a number of ways. For instance, one section of the orchestra can alternate with another section … [Or] each section actually melds into the other, the woodwind chord dissolving into the string chords. (270)

Rimsky-Korsakov ([1912] 1964) stresses the importance of understanding the musical context in terms of whether the material evokes a sense of gradual progression or a discrete change:

> The aim of a composer is closely allied to the form of his work, to the aesthetic meaning of its every moment and phrase considered apart, and in relation to the composition as a whole. The choice of an orchestral scheme depends on the musical matter, the colouring of preceding and subsequent passages. It is important to determine whether a given passage is a complement to or a contrast with what goes before and comes after, whether it forms a climax or merely a step in the general march of musical thought. (98)

Contrasting groups of the orchestra can be traced back to Renaissance antiphonal music, in which opposing vocal choirs alternated musical phrases, often in call and response structure. Different choirs in antiphonal dialogue were also accompanied by the organ and other groups of instruments. Following this tradition, orchestration manuals often describe the contrast of instrumental families in phrase-structural dialogue as antiphonal. For example, Read (1979) draws a historical connection in Bruckner's use of antiphonal scoring using orchestral contrasts, such as in the first movement of his Ninth Symphony:

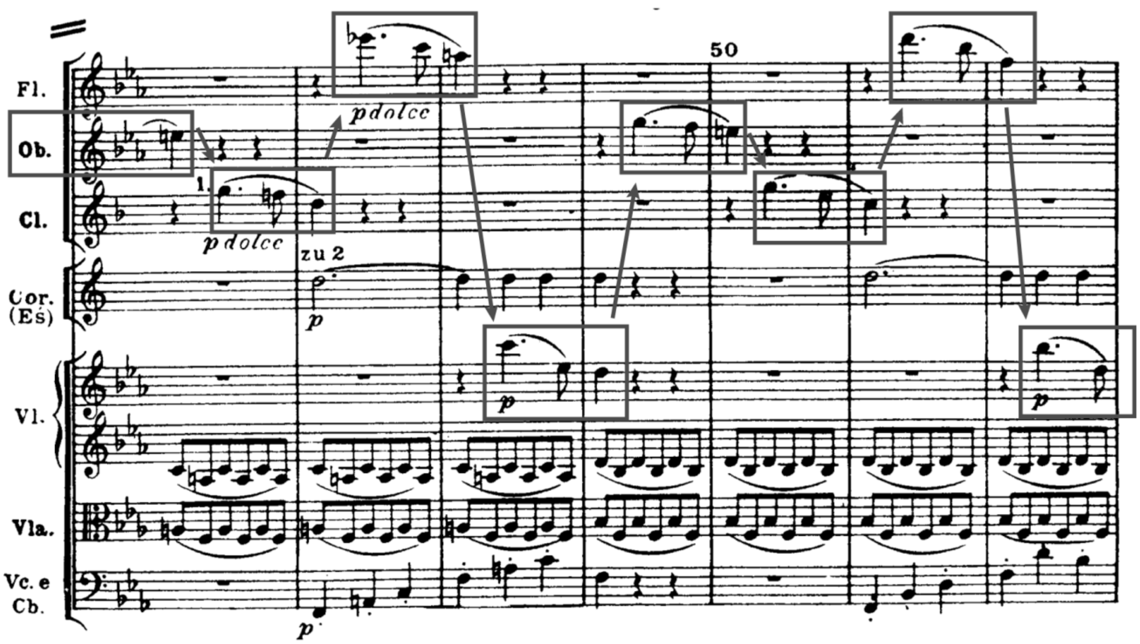
> Bruckner conceived and executed his tonal masses in much the same manner that Gabrieli's elaborate seventeenth-century polyphony contrasted voices, brass instruments, and organ. In Bruckner's orchestral works this antiphony, or alternation by choirs, led to his pitting brasses against woodwinds, to having strings answering brasses, woodwinds and brasses echoing strings. (107)

Similarly, Kennan and Grantham (2002) outline the division of orchestra into groups as a special orchestral device. Referencing Gabrieli's divided choir technique as an early prototype, they describe the use of the alternation of orchestral groups "for antiphonal effects and broad contrasts of weight or color" (325).

Another special effect growing out of the notion of antiphonal contrasts involves reiterating musical materials with varying orchestration, creating the impression of the material being passed around the orchestra. Adler (2002) describes Beethoven's extensive usage of this technique, which involves passing motivic material to various instruments or instrumental combinations through discrete timbral steps:

> Following is a famous and clear example of antiphonal writing from the first movement of Beethoven's Symphony No. 3. Beethoven was very fond of assigning a motivic gesture to different members of the wind and string sections and then summing up the passage with a cadential tutti phrase. … Beethoven provides instant contrast … by "throwing around" a three-note motive; first played by the oboe, it is then repeated at different pitch levels by the clarinet, flute, and first violin. (273)

We annotated the motive shifting between instruments in Example 3. Beethoven repeats the sequence of instruments as the harmonic support and melodic contour changes.




**Example 3. Timbral shifts between instruments involving a three-note motive (annotated with grey boxes and arrows) in Beethoven, Symphony 3, I, mm. 46−52.**

A similar procedure is timbral echoing, which involves repeating or reiterating a musical phrase with varied orchestration to create a sense that the second grouping is more distant than the first. Unlike an antiphonal relationship that exploits maximal instrumental dissimilarity, timbral echoes require enough contrast to create a sense of timbral distance but not enough to produce too strong of a discontinuity. Rimsky-Korsakov ([1912] 1964) provides a detailed description:

> In echo phrases, that is to say imitation entailing not only decrease in volume of tone but also an effect of distance, the second instrument should be weaker than the first, but the two should possess some sort of affinity. An echo given to muted brass following the same phrase not muted produces this distant effect. Muted trumpets are eminently suited to echo a theme in the oboes; flutes also may imitate clarinets and oboes successfully. A wood-wind instrument cannot be used to echo the strings, or vice versa, on account of the dissimilarity in timbre. Imitation in octaves (with a decrease in resonance) creates an effect resembling an echo. (110)

In addition to highlighting timbral differences, composers also make use of gradual changes in instrumental color to provide a sense of timbral continuity, which we term progressive orchestration. Schnittke (2006) calls one example of this technique "timbral modulation," which he describes as a "counterbalance to timbral contrast" (164). The method involves a succession of gradually changing blended or integrated timbres, capable of unifying all the transitional instrumental combinations into a coherent grouping. Rimsky-Korsakov ([1912] 1964) provides a description of smoothly progressing from one instrument to another through blended intermediary instrument groupings:

> A similar operation is used in scoring passages covering the entire orchestral scale, or a great portion of it. When one instrument is on the point of completing its allotted part, another instrument takes up the passage, starting on one or two notes common to both parts, and so on. This division must be carried out to ensure the balance of the whole passage. (108)

Adler (2002) describes this technique for scoring material over a wide pitch range with the use of instrumental combinations to "bridge the registral gap" (599). As a result, the orchestral color gradually changes as instruments are introduced and others are dropped.

A detailed description of progressive orchestration is found in *Orpheus in New Guises* by Erwin Stein in relation to Schoenberg's "Farben" from *Five Orchestral Pieces*, Op. 16. Stein emphasizes the importance of preserving the aural connections among the changes in instrumental color:

> The subtly changing colors on a lake's lightly rippled surface are painted by changing orchestral timbres of a five-part chord. The instruments sustaining the chord give way to others of a slightly different color. ... In this way a climax of changing colors is built up, which quickly recedes until the original pace returns. Delicate short passages of other instruments occasionally shade the colors of the quasi-sustained chord—shadows of passing birds, as it were. ... A very delicate balance has to be maintained; and only a sensitive mind [allied] with acute ears will discern and enjoy the interplay of softly shaded tone colors." (Read 1979, 163)

In "Farben," Schoenberg minimizes the harmonic and melodic progression, bringing the subtle shifting among orchestral colors to the fore. This work has been discussed as an example of Schoenberg's unique conception of *Klangfarbenmelodie* (tone color melody), which differs from the more pointillistic and melodic approach of Webern and his followers (Read 1979; Kennan and

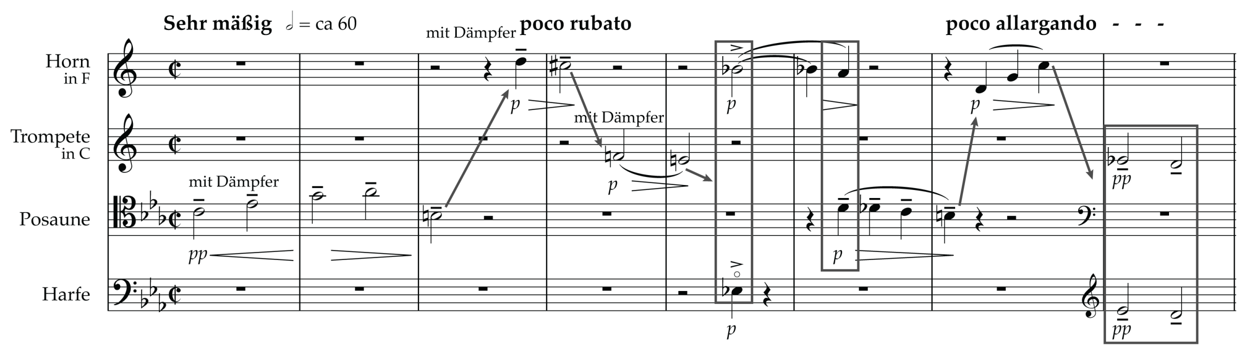
Grantham 2002). In this technique, "melodic lines that formerly would have been taken by a single instrument are now sometimes divided among several. In serial music, the row may even be fragmented to the point where each note is given to a separate instrument" (Kennan and Grantham 2002, 302), for example, in Webern's *Symphony,* Op. 21 and *Variations for Orchestra*, Op. 30. Note, however, that Webern's timbral transitions can also be more continuous, such as in his orchestration of the "Ricercar" from Bach's *Musical Offering* (also discussed below), in which the changes tend to be confined within instrumental families to preserve the continuity of the contrapuntal lines and the distinction between them through opposing choirs. Both Schoenberg and Webern's approaches result from an increased interest in the twentieth century in employing timbral relationships, involving both gradual and sudden shifts in timbre, to delineate musical materials or as a principle compositional element (Mathews 2006). This increasing emphasis on timbre as a primary musical parameter is what composer John Rea terms "prima facie" orchestration in contrast to "normative" orchestration in which timbre is used to reinforce or "color" structures primarily based on melody, harmony, rhythm and meter (John Rea, pers. comm.).

*Auditory scene analysis and segmentation studies*

In terms of auditory scene analysis, orchestral contrasts and progressive orchestration implicate segmental grouping processes, in which listeners group or "chunk" musical streams into units such as phrases and themes (see Figure 1). According to the Gestalt principle of similarity, similar sounds are grouped together and are segmented into chunks that are bounded by acoustical dissimilarities. A succession of gradual changes creates a sense of continuity, whereas discontinuities promote chunking of musical units. Therefore, musical segments are formed on the basis of similarities in register, texture, and instrumentation (i.e., timbre); changes in one or more of these musical features signal boundaries at various levels of the musical hierarchy.

Lerdahl and Jackendoff's (1983) generative theory of tonal music proposed a series of grouping preference rules that reflect how listeners' perceptually structure musical sequences. Two Gestalt principals of proximity and similarity underlie the rules, most of which result from a change or discontinuity in an auditory attribute, including register, dynamics, articulation, note duration, and timbre. Deliège (1987) experimentally tested the extent to which listeners segmented musical phrases in accordance with Lerdahl and Jackendoff's grouping rules. She found that timbral discontinuities (i.e., changes in instrument timbre) were among the changes that listeners, both musicians and nonmusicians, detect most often in short phrases. Listeners also segment large-scale sections of contemporary works on the basis of marked contrasts in instrumentation and texture (Deliège 1989). Therefore, timbral discontinuities promote the creation of perceptual boundaries, whereas continuities promote the chunking of events into coherent units at various levels of the structural hierarchy.

Specific evaluation of the role that timbre plays in segmental structuring is limited in the music-theoretical and perceptual scholarship. More research in this area would be useful to explore various timbral connections and their perception by listeners. One potential avenue for investigation is the notion of timbral distance used to create echo effects. In addition to Rimsky-Korsakov's suggestion for the use of muted trumpets (discussed above), what techniques have composers used to create timbral echoes and how do these relate to perceptual principles? There are several cues to distance perception including intensity, direct-to-reverberant energy ratio and spectrum. More distant sounds are less intense, have a lower ratio of direct sound energy to reverberant sound energy, and have less energy in the higher frequencies due to absorption in the air and the absorbing characteristics of reflective surfaces in rooms (Zahorik, Brungart, and Bronkhorst 2005). In relation to the *Klangfarbenmelodie*-type approaches of Schoenberg and Webern, of particular interest is the extent to which listeners hear connected melodies through the sequence of instrument timbres and blends, such as in Webern's scoring of the "Ricercar" from Bach's *Musical Offering* (see Example 4). How well are listeners able to perceive Webern's planned melodic connections in this piece, as he discussed in reference to this work: "my orchestration is intended … to reveal the motivic coherence" (Mathews 2006, 158)? On the other hand, what degree of timbral difference for pointillistic fragmentation is required to induce perceptual discontinuity?




**Example 4. Annotated arrows show connections between instruments and boxes show instrument blends. Bach Johann Sebastian (2. Ricercata) in 6 voices from "Das musikalische Opfer" orchestrated by Anton Webern, mm. 1-8.**
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More research is also needed to investigate how orchestration interacts with other musical parameters to shape musical form and musical expression. Large-scale orchestral shaping, such as the sudden contrast between the full orchestra and a soloist, has been found to contribute to strong emotional responses (Guhn, Hamm, and Zentner 2007; Sloboda 1991; Panksepp 1995). In order to provide a taxonomy and conceptual framework for these changes in instrumental texture and timbre, Goodchild (2016) studied *orchestral gestures,* which she defined as large-scale, goal-directed instrumental shaping that coordinates disparate musical elements, creating a sense of agency and emotional force. She proposed a typology defined by changes in instrumentation in terms of time course (gradual or sudden changes) and direction (additive or reductive changes). Therefore, orchestral gestures result from segmental grouping contrasts or from their absence through progressive changes or continuity. The four types relate to the descriptions in orchestration treatises and manuals of an orchestral crescendo (gradual addition), the reverse process (gradual reduction), and contrasts in instrumental texture and timbre including a rapid switch to full forces (sudden addition) and the drop-off to a contrasting subgroup or soloist (sudden reduction). In an exploratory listening study (Goodchild, Wild, and McAdams 2017), the emotional intensity response profiles of musician and nonmusician listeners were found to differ for the four gestural types. For the gradual addition type, the emotional intensity ratings climbed steadily following the increasing growth of instrumental texture (number of instrumental parts) and loudness. For the sudden addition gestures, there was a slight tendency for musicians, but not nonmusicians, to anticipate the moment of sudden change with heightened emotional responses. The responses to the gradual and sudden reductive excerpts featured a plateau of lingering high emotional intensity, despite the decrease of most musical features, including loudness, spectral centroid (timbral brightness), instrumental texture, and onset density (number of attacks per beat). Figure 3 contains a visualization as an interpretive analytical tool, with average emotional intensity ratings of musicians and nonmusicians and musical features extracted from the score and from an audio recording (Goodchild 2016). Future research in this area could explore instances where orchestral shaping, such as an abrupt change in texture or timbre, does not coordinate with other musical processes, such as phrase structure. The music-theoretical meanings and the resulting perceptual effects have yet to be explored.

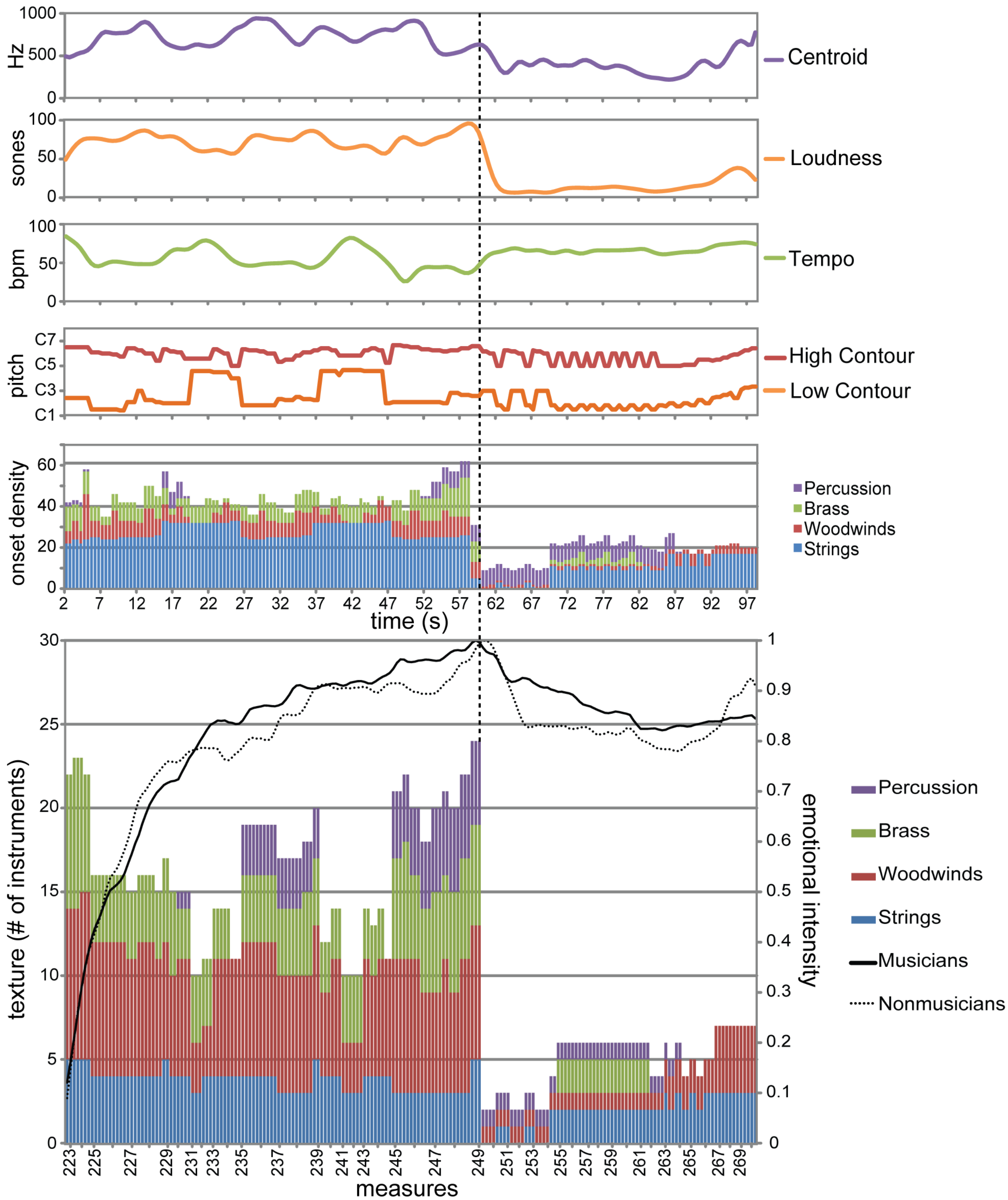


**Figure 3. Visualization of Bruckner, Symphony 8, I, mm. 221-270, with spectral centroid, loudness, tempo, pitch range (ambitus), onset density, instrumental texture, and emotional intensity ratings. The vertical dotted line indicates the moment of sudden change in instrumental texture.**

## Discussion

In this chapter, we have demonstrated how many orchestration practices, including blending instrumental timbres, segregating and layering instrumental parts, and creating contrasts and continuity through changes in instrumentation, can be understood in relation to auditory grouping principles. Research on auditory scene analysis and timbre perception contextualizes seemingly esoteric prescriptions in orchestration treatises and provides many implications for developing orchestration theory grounded in perceptual principles. Within each of the sections above, we have suggested specific avenues for future interdisciplinary research, which necessitates the confluence of the areas of music theory, orchestration, and psychology. In general, one major research area would involve the investigation of the fragility of these orchestration effects. For example, to what extent is a blend under the control of the conductor and the performers? How can room acoustics and recording techniques influence the perception of blend, segregation, or contrasts? How robust are these orchestration effects in relation to the attention and memory of the listener? Further systematic study in these areas will potentially change the way in which we understand and teach orchestration.

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