Factors Influencing Musical Tension Processing

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Abstract

In essence, music is nothing but tension and release. Musical tension bridges objective sound and subjective experience, constituting the prerequisite and foundation for musical emotion generation. The factors influencing musical tension processing primarily derive from two dimensions: the object and the subject. Research findings indicate that acoustic elements and tonal structure serve as acoustic cues influencing the induction of musical tension, whereas cultural background and musical ability are individual factors affecting listeners' processing of tension. Future research necessitates in-depth investigation into tension induced by temporal structure and long-term tonal structure and its underlying mechanisms, which will contribute to deepening our understanding of musical tension and emotion processing.

Full Text

Preamble

Factors Influencing the Processing of Musical Tension

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Abstract

Music is nothing but tension and release. Musical tension serves as a bridge between objective sound and subjective experience, forming the prerequisite and foundation for musical emotion. Factors influencing the processing of musical tension primarily originate from two aspects: the musical object and the listener. Research has revealed that acoustic elements and tonal structure are the sound cues that influence the elicitation of musical tension, while cultural background and musical ability are individual factors that affect how listeners process tension. Future research should investigate tension induced by temporal structures and long-term tonal structures and their underlying mechanisms, which will deepen our understanding of musical tension and emotional processing.

Keywords: musical tension; tonal structure; acoustic elements; cultural background; musical ability

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1 Introduction

Music is the language of emotion. In daily life, people often regulate their emotions, relieve stress, and derive enjoyment through music (Juslin & Sloboda, 2010). During music listening, individuals not only perceive and experience subtle emotional changes conveyed by music (Shen et al., 2018; Zentner et al., 2008) but also activate brain regions and neural circuits similar to those involved in processing general emotional events (Koelsch, 2018). Evidently, music possesses powerful emotional force. How, then, does musical sound evoke musical emotion?

As Hindemith stated, "Music is nothing but tension and release" (cited in Zhang, 2002), and tension-relaxation represents the most direct expression in music. Tension is an emotional state associated with conflict, dissonance, instability, and uncertainty (Lehne & Koelsch, 2015b). Although people often associate tension in daily life with negative emotions such as fear, anxiety, and depression, tension in music lacks distinct negative valence and represents a valence-independent dynamic experience (Schubert, 2010). In lay terms, musical tension resembles the feeling evoked when watching a suspense film where the plot thickens but the truth remains unclear—a sensation also termed "suspense" (Granot & Eitan, 2011; Lehne & Koelsch, 2015b). Conversely, the resolution of such suspense generates feelings of relaxation and closure. It is precisely the continuous alternation of tension-relaxation patterns that drives musical development. Serving as a bridge between objective sound and subjective experience, musical tension forms the basis for musical emotion (Berry, 1976; Hindemith, 1937) and constitutes a prerequisite for generating intrinsic musical meaning (Jiang, 2016).

Given the importance of tension in musical emotion perception, numerous theoretical models and empirical studies have explored musical tension in depth. This paper examines the sound cues and individual factors influencing musical tension processing from both object and subject perspectives. First, by reviewing theoretical models and empirical research on musical tension, we reveal the significant role of acoustic elements and tonal structure in eliciting musical tension and their underlying neural mechanisms. Second, from the perspective of individual experience, we analyze how cultural background and musical ability affect listeners' processing of tension and the reasons behind these effects. Finally, we discuss current limitations and future directions in musical tension research, particularly emphasizing the need to further investigate tension induced by musical structures and its mechanisms.

2 Acoustic and Structural Factors Influencing Musical Tension

Composers organize discrete pitch elements into complex, structurally organized sound sequences according to musical rules. On one hand, acoustic properties of individual elements such as dynamics, tempo, and consonance can influence the elicitation of musical tension. On the other hand, musical structure, through the transformation and arrangement of pitches and chords, affects the hierarchical organization of tension-relaxation patterns.

2.1 Acoustic Elements

Sensation-based tension-relaxation models emphasize the influence of physical sound properties on tension. For isolated musical events, the smoothness or roughness of certain frequency intervals in overtone series and between pitches determines perceived tension (Hutchinson & Knopoff, 1978). The vibration frequencies of dissonant chords interfere with auditory receptors in the basilar membrane of the inner ear (Helmholtz, 1913). For developing musical sequences, the compatibility between the current musical event and its context determines the listener’ s tension. The Auditory Short-term Memory (ASTM) model focuses not only on isolated musical events but also considers musical context, interpreting the processing of musical events in a “perceptually driven” manner as the cumulative result of frequency attributes of pitches in short-term memory (Bigand et al., 2014; Collins et al., 2014; Leman, 2000).

Building upon this foundation, Farbood (2012) proposed a Parametric, Temporal Model of Musical Tension. This model incorporates multiple musical parameters—including harmony, pitch height, melodic expectation, dynamics, onset frequency, tempo, meter, rhythmic regularity, and syncopation—to predict musical tension. Additionally, based on the concept of moving perceptual time windows and trend salience, the model determines the contribution of short-term memory to musical tension by comparing the match between tension trends in memory and attention windows. By assigning weights to different musical parameters and comprehensively measuring temporal dynamics during musical development, the model predicts tension for complex musical stimuli.

Researchers typically employ continuous response measurement to investigate the influence of acoustic elements on musical tension. This method demonstrates good reliability and validity (Schubert, 2010), accurately recording listeners’ tension responses to specific sound events within a sequence while mapping the fluctuating curve of tension development throughout an entire piece. Krumhansl (1996) presented listeners with the first movement of Mozart’ s Piano Sonata in E major, K. 282, and used continuous response measurement to examine the effect of loudness on tension elicitation. Results indicated a significant positive correlation between musical loudness and tension—higher loudness elicited stronger tension. Subsequent studies not only replicated this finding (Ilie & Thompson, 2006; Misenhelter, 2001) but also discovered that loudness elicits musical tension more rapidly than other parameters (Farbood & Finn, 2013) and exerts a greater influence on tension overall (Granot & Eitan, 2011). From a biological perspective, loud sounds often serve as warning signals for potential danger, suggesting that listeners may develop conditioned responses to them.

Timbre also constitutes an important factor influencing tension elicitation. Research has shown that variations in roughness, brightness, density (Pressnitzer et al., 2000), and consonance (Toiviainen & Krumhansl, 2003) all elicit different degrees of tension. Farbood and Price (2017) more precisely examined which timbral dimensions contribute most critically to tension, finding that roughness, inharmonicity, and spectral flatness correlate more closely with tension than spectral centroid or spectral deviation. Additionally, other acoustic elements such as register (Costa & Nese, 2020; Granot & Eitan, 2011; Ilie & Thompson, 2006), pitch contour (Bigand et al., 1996; Farbood, 2012; Krumhansl, 1996), and tempo (Farbood, 2012; Ilie & Thompson, 2006; Madsen et al., 1997) have been verified as influencing tension. Only recently have Farbood (2012) and Farbood and Finn (2013) comprehensively examined the influence of multiple acoustic parameters on tension, discovering that listeners' experienced tension curves almost perfectly matched those predicted by quantifying multiple musical parameters. These findings validate acoustic parameter-based tension models, highlighting the importance of multiple acoustic parameters and their temporal windows of influence in short-term memory for quantifying musical tension.

Although these studies partially validate the influence of acoustic elements on tension, most psychoacoustic factors represent physical properties common to general auditory stimuli and belong to relatively low-level auditory processing. Musical listening is essentially an active process of sound sequence processing, constantly accompanied by the construction of mental representations that extract higher-level structures from surface auditory events. Therefore, focusing solely on acoustic elements is insufficient, as this approach may overlook important attributes that distinguish music from other auditory stimuli.

2.2 Tonal Structure

Cognitive models of tension-relaxation explain how tonal structure in music influences tension. Lerdahl and Jackendoff (1983) first demonstrated the hierarchical organization of tension-relaxation patterns in their Generative Theory of Tonal Music (GTTM) through prolongational reduction trees, embedding local tension-relaxation patterns within longer-term patterns. They proposed that musical events occupying more important positions in the tonal hierarchy elicit weaker tension, while less important events generate stronger tension. Lerdahl (2001) further proposed Tonal Pitch Space Theory (TPS), which calculates spatial distances between chords from two perspectives: intra-tonal distance (determined by proximity to the tonal center) and inter-tonal distance (determined by the number of shared tones between keys), with greater spatial distances producing stronger tension.

Building on this foundation, Lerdahl and Krumhansl (2007) proposed the Tonal Tension Model (TTM), which integrates four components—prolongational structure, pitch space model, surface-tension model, and attraction model—to quantify tension values for each chord through formulas. The prolongational structure and pitch space distance continue the tension theories of Lerdahl and Jackendoff (1983) and Lerdahl (2001). The surface-tension model considers the effects of chord inversions (chords with the third, fifth, or seventh in the bass) and melodic tones in the upper voice on tension. Pitch attraction refers to the gravitational pull of one pitch toward another in tonal music, with stronger attraction eliciting greater tension. These tension models both identify key events that convey musical tension and clearly demonstrate the unique role each chord plays in advancing tension development throughout a piece. Thus, the hierarchical unfolding of tension-relaxation patterns depends simultaneously on local tonal organization and long-distance tonal relationships.

To investigate the influence of chord stability on musical tension, Bigand et al. (1996) employed harmonic sequences of triads as experimental materials, manipulating the harmonic structure of middle chords (their vertical/horizontal organization) to create either seven diatonic chords (constructed from scale degrees) or non-diatonic chords (containing one or more non-scale tones). According to the hierarchical nature of tonal structure, all diatonic chords possess higher stability than non-diatonic chords; among diatonic chords, the tonic chord (built on the tonic) exhibits the highest stability, followed by the dominant chord (built on the dominant), with the leading-tone chord (built on the leading tone) being the least stable. After listening, participants rated the tension of the middle chord. Results demonstrated that more stable harmonic structures elicited weaker tension: the tonic chord produced the least tension, followed by the dominant chord, other diatonic chords, and finally non-diatonic chords. Similarly, Steinbeis et al. (2006) manipulated the stability of final chords in musical phrases and found that listeners rated high-stability chords as significantly less tense than low-stability chords. Moreover, changes in melodic/harmonic structure exert more important effects on musical tension than acoustic elements (Krumhansl, 1996; Lehne et al., 2013). Overall, these results support tonal-based tension-relaxation models and validate the influence of chord structural stability on musical tension.

Beyond local harmonic structure, Bigand and Parncutt (1999) further investigated the influence of long-term harmonic structure on musical tension. Researchers selected a chord sequence containing a modulation and presented it ending at different chord positions, then asked participants to rate the tension of the final chord. Results indicated that musical tension was primarily determined by local cadential patterns, with long-term harmonic deviation failing to elicit tension and long-term harmonic resolution unable to resolve tension. These findings did not validate the hierarchical tension processing model proposed by Lerdahl and Jackendoff (1983) in GTTM. This may be because the temporal scope of modulation’ s influence on tension is relatively narrow; when returning to the home key after modulation, the tonic chord may be perceived as a tonal deviation, paradoxically increasing tension. Unfortunately, these studies did not employ rigorous experimental designs to control for acoustic confounds when manipulating tonal structure. Future research could 借鉴 experimental control methods used in musical syntax processing studies (e.g., Koelsch et al., 2007; Poulin-Charronnat et al., 2006; Zhang et al., 2018). On one hand, tonal-harmonic context could be altered while keeping the acoustic properties of target chords constant; on the other hand, secondary or subdominant chords could substitute for Neapolitan or secondary dominant chords to control for the frequency of target chords in the context and the number of shared tones with context chords, thereby reducing the influence of acoustic novelty.

Several studies have also examined the neurophysiological mechanisms underlying musical tension processing. Bai et al. (2016) manipulated mode structure (major vs. minor) and harmonic stability (high vs. low stability), asking participants to subjectively rate musical tension while recording physiological indices such as skin conductance, finger pulse rate, and finger temperature. Results showed that in major mode conditions, unstable harmonic structures elicited stronger tension than stable structures, manifested physiologically by greater skin conductance and higher finger pulse rate. However, in minor mode conditions, no significant differences emerged between stable and unstable harmonic structures in either tension ratings or physiological responses. This may reflect listeners’ weaker sensitivity to hierarchical structures in minor-key music compared to major-key music (Vuvan & Schmuckler, 2011). These findings indicate that musical tension correlates with increased skin conductance and finger pulse rate, consistent with physiological mechanisms of emotion processing.

Steinbeis et al. (2006) and Steinbeis and Koelsch (2008) also investigated electrophysiological responses to musical tension, employing a syntactic rule-violation paradigm. They found that syntactically irregular chords elicited larger early right anterior negativity (ERAN) and N5 components compared to regular chords, suggesting a close relationship between musical tension and expectancy violation. However, these studies did not strictly control for non-diatonic tones in target chords or the frequency of irregular chords in the musical context, thus confounding acoustic factors. Additionally, Lehne et al. (2014) used functional magnetic resonance imaging (fMRI) to examine brain regions involved in musical tension processing. Participants listened to piano works while continuously rating tension experiences. Correlation analyses between brain activation and tension ratings identified the left orbital part of the inferior frontal gyrus and right amygdala as key regions for musical tension processing. Unfortunately, this study did not distinguish contributions of psychoacoustic versus tonal structural factors to tension. While cognitive neuroscience techniques provide powerful tools for investigating neural mechanisms of musical tension, existing EEG and neuroimaging studies remain limited. Future research should more deeply focus on musical structure, employing analytical methods such as time-frequency spectra, phase coherence, and functional connectivity to reveal neural mechanisms underlying tension processing. Moreover, magnetoencephalography (MEG) offers both high temporal and spatial resolution, providing a promising technique for future studies to more precisely examine how musical tension evolves over time and to comprehensively explore how long-term musical structures influence emotional development and their neural mechanisms.

In summary, "physicalist" and "cognitivist" tension models respectively predict and explain musical tension from acoustic elements and musical structure perspectives, receiving support from behavioral and neurophysiological studies. However, because experimental materials have confounded contributions of acoustic elements and tonal structure to tension, future research should employ more rigorous experimental designs to accurately separate their effects.

3 Individual Factors Influencing Musical Tension Processing

Musical tension represents an intermediate link between objective sound stimuli and subjective experience. Therefore, beyond acoustic elements and tonal structure, listeners' actual experienced tension is also influenced by individual differences such as cultural background and musical ability. The following sections elaborate on these two aspects.

3.1 Cultural Background

Listeners' musical experience formed within specific cultural contexts influences musical tension processing. Wong et al. (2009) selected three participant groups with exclusively Indian music backgrounds, exclusively Western music backgrounds, or both backgrounds. Western and Indian music systems employ different organizational rules, resulting in distinct tonal hierarchies. All three groups listened to both Indian and Western music, then rated tension after each piece. Results showed that listeners with only Indian music backgrounds perceived Western music as more tense, those with only Western backgrounds perceived Indian music as more tense, while bimusical listeners showed no difference in tension ratings between the two musical styles. Jiang et al. (2017) replicated this finding, showing that listeners with Western musical backgrounds rated Indian music as more tense than Western music. These results demonstrate that listeners experience stronger tension when encountering music employing tonal structures from outside their own cultural background.

The influence of cultural background on tension processing likely stems from differences in mental representations of modal structures. Research indicates that prolonged exposure to a particular musical culture enables implicit acquisition of that culture' s dominant structural rules (Deutsch, 2013; Trainor & Hannon, 2013). This implicit knowledge, gained through enculturation, allows listeners from different cultural backgrounds to develop unique internal schemas that facilitate their perception of tension-relaxation patterns within that cultural context. This aligns with findings from music emotion research. McDermott et al. (2016) studied Tsimane' people living in the Amazon rainforest with minimal exposure to external music, asking them to rate the pleasantness of consonant and dissonant chords. Results showed no difference in pleasantness ratings between consonant and dissonant chords for the Tsimane', whereas control listeners with Western musical backgrounds rated consonant chords as significantly more pleasant than dissonant chords.

Notably, Chinese listeners possess "bimusical ears."In China, people regularly encounter both Western major-minor music (e.g., "March of the Volunteers") and traditional Chinese pentatonic music (e.g., "Jasmine Flower"). Consequently, Chinese listeners can represent two different tonal hierarchies and process tension in both musical cultures. However, those unfamiliar with Chinese pentatonic music may struggle to represent its structural organization, resulting in insensitivity to tension induced by its modal structures. Additionally, research suggests that cultural background influences tension processing through interactions between timbre and other musical elements, with listeners potentially experiencing greater tension when encountering timbres from outside their own musical culture (Jiang et al., 2017). Future research could therefore investigate the relationship between Chinese listeners'bimusical background and tension processing through cross-cultural comparisons using native instruments and modes.

3.2 Musical Ability

Even individuals without musical training can process musical tension. Bigand and Parncutt (1999) extracted chords from the first two phrases of Chopin' s Prelude in E major and presented them at equal time intervals to participants, who rated the tension of each chord. Results showed that non-musicians could effectively perceive tension changes in chord sequences. Similar studies have demonstrated that non-musicians can process tension not only in simple chord sequences (Bigand & Parncutt, 1999; Bigand et al., 1996) and monophonic melodies (Farbood, 2012; Wong et al., 2009) but also in real musical excerpts (Lehne et al., 2013; Lehne et al., 2014). This capability arises for two reasons: first, people universally perceive acoustic physical properties present in everyday auditory events such as tempo and dynamics, enabling them to detect important acoustic cues for musical tension; second, through extensive passive exposure, ordinary listeners implicitly acquire musical organizational rules (Jiang et al., 2017; Koelsch et al., 2013; Wong et al., 2009), allowing them to process tension induced by tonal structures.

Although non-musicians can process musical tension to some degree, musical training exerts an influence. Bigand et al. (1996) compared musicians and non-musicians rating tension in chord sequences, finding that musicians tended to utilize hierarchical harmonic structure cues, whereas non-musicians relied more on psychoacoustic cues. Subsequent research not only replicated this finding (Granot & Eitan, 2011; Toiviainen & Krumhansl, 2003) but also revealed that musicians' tension ratings of chord sequences more closely matched predictions from cognitive models (Bigand & Parncutt, 1999). These studies collectively demonstrate that musicians are more adept than non-musicians at using structural cues to process tension, likely because musical training enhances structural processing abilities. Indeed, research on musical syntax shows that musicians exhibit larger early right anterior negativity (ERAN) in response to syntactically irregular chords than non-musicians, reflecting early automatic detection of structural violations (Koelsch et al., 2002). Musicians' early automatic processing advantages for musical structures may render them more sensitive to tension induced by tonal structures.

Research has also examined tension processing in individuals with congenital amusia. Amusics, colloquially "tone-deaf," exhibit pitch processing deficits, including inability to discriminate subtle pitch differences (Jiang et al., 2019; Zhou et al., 2017) and impaired processing of tonal structure rules (Jiang et al., 2016; Zhou et al., 2019). Jiang et al. (2017) compared amusics and control participants, all with Western musical backgrounds, who listened to Western major-minor melodies and Indian raga melodies and rated tension. Results showed that amusics gave similar tension ratings to Western and Indian music, whereas controls rated Indian music as significantly more tense than Western music. For Western music, amusics perceived significantly higher tension than controls, while no group difference emerged for Indian music. This indicates that amusics have difficulty processing tension induced by major-minor tonal structures, likely due to impaired mental access to tonal structure rules.

Thus, whether for extensively trained musicians or amusics with pitch processing deficits, musical ability primarily influences tension processing for structure-induced rather than acoustically-induced tension. It is precisely this structure-induced tension that distinguishes music from other sounds and enables the communication of more subtle and complex emotions. Given that tension processing constitutes an important aspect of musical aesthetics, future research could further explore whether musical ability influences listeners' perception of aesthetic emotions in music.

5 Summary and Outlook

Existing behavioral and neurophysiological research demonstrates that musical tension processing is influenced not only by sound cues such as acoustic elements and tonal structure but also modulated by individual factors including cultural background and musical ability. These findings have greatly enriched and advanced our understanding of musical tension and emotion. Through reviewing previous research, we find that structural organization holds special significance for music and importantly influences tension processing. However, few studies have addressed the relationship between temporal structure and tension or tension induced by multi-level hierarchical structures across larger time scales in musical works. Moreover, the internal mechanisms through which musical structure elicits tension lack in-depth discussion. Therefore, future research should explore several areas more deeply:

First, musical events combine into hierarchical structural organizations along both pitch and temporal dimensions based on their respective stability (Lerdahl & Jackendoff, 1983; Rohrmeier, 2011). Harmonic structure and metrical structure processing represent two important aspects of music cognition (Fitch, 2013; Koelsch, 2013; Sun et al., 2018; Sun et al., 2020) and constitute important cues for eliciting musical emotional experiences (Koelsch, 2014; Witek et al., 2014). Current research has primarily focused on tension induced by harmonic structure, neglecting the importance of temporal structure. In fact, music is the art of time; even percussion music lacking pitch dimensions can constitute excellent musical works, but information without temporal dimensions cannot be called music (Jiang et al., 2014). Hierarchical organization of temporal structure in music manifests in metrical accent patterns (e.g., duple meter combines strong and weak beats). When syncopation disrupts the alignment of rhythmic accents with metrical accents, this breakdown of the strong-weak relationship may become an important cue for eliciting tension. Additionally, music typically involves interwoven pitch and temporal information (Prince, 2014a, 2014b), and how these two dimensions jointly elicit musical tension remains unknown. Investigating these issues will help more comprehensively reveal the formation and development of musical tension.

Second, real musical works are sound sequences with hierarchical structures unfolding across multiple time scales. Generative theory also proposes that local tension-relaxation patterns are nested within global patterns, thereby eliciting hierarchical tension experiences (Lerdahl & Jackendoff, 1983). However, due to the scarcity of research on long-term hierarchical structures in music, this key issue remains poorly validated. Recent studies have begun examining listeners' processing of nested musical structures (Koelsch et al., 2013; Ma et al., 2018a, 2018b; Zhou et al., 2019), confirming the psychological reality of cognitive processing for long-term musical structures. The nested structure paradigm not only provides an excellent research framework for investigating long-term tension but also leads us to expect that music listening indeed involves richer hierarchical tension-relaxation patterns. Future research should employ more ecologically valid musical materials containing multi-level nested structures, combined with real-time dynamic behavioral measurement, to reveal tension-relaxation patterns induced by long-term hierarchical structures and provide empirical support for generative theory.

Finally, the internal mechanism through which musical structure elicits tension via expectation remains unclear. Numerous studies indicate that the brain actively and continuously predicts auditory stimuli, updating mental representations based on new input (Friston, 2010; Lu & Hou, 2019). After a musical passage begins, listeners first form mental representations based on heard sounds and use these to predict upcoming events (Koelsch, 2014; Koelsch et al., 2019). On one hand, when mental representations point clearly to a specific outcome but the subsequent event violates this expectation, the listener' s prediction is disrupted, and prediction errors elicit tension (Lehne & Koelsch, 2015b). On the other hand, when an event makes subsequent musical development difficult to predict, lower predictability leads to ambiguous mental representations, generating tension before the next event occurs (Lehne & Koelsch, 2015a; Margulis, 2005). As the probabilistic prediction hypothesis (PPH) suggests, higher information entropy in music leads to lower predictability and greater prediction difficulty for listeners (Hansen & Pearce, 2014; Pearce, 2018). Thus, prediction difficulty and prediction error during music listening may constitute internal mechanisms for eliciting higher tension. However, the relationships among musical structure, expectation, and tension urgently require further empirical investigation.

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The influences of musical cues and individual differences on the processing of musical tension

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Abstract: The pattern of tension-relaxation is an essential component in music. Musical tension, building a bridge between objective sound and subjective experience, is important for the generation of musical emotion. On the one hand, musical tension is influenced by acoustic elements and structural organizations of tonal hierarchy, which is supported by theoretic models and empirical studies. On the other hand, musical tension experienced by listeners is also affected by individual differences, such as cultural background and musical ability. Future studies should pay more attention to musical tension induced by temporal structure and large-scale tonal structure. Meanwhile, the mechanism of tension induction also needs to be examined, which will be helpful to deepen our understanding of tension and emotion processing in music.

Key words: musical tension; tonal structure; acoustic elements; cultural background; music ability

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