Exploring the relationship between timbre and perceived musical tension

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Introduction

Musical tension is described as the ongoing shifts between tension and resolution that are perceived when listening to Western tonal music (Lenhe, Rohrmeier, Gollmann, & Koelsch, 2013). Most of the research on musical tension has explored the influence of several musical elements, such as tonality, harmony, pitch height, horizontal motion, and dynamics (Bigand, Parncutt, & Lehrdahl, 1996; Farbood, 2012; Lenhe et al., 2013). These musical elements contributed to musicians and non-musicians' perceptions of musical tension differently (Bigand et al., 1996; Farbood, 2012). For example, perception of musical tension was more influenced by tonality and harmony for musicians (Bigand et al., 1996). Non-musicians, however, were more influenced by pitch height and horizontal motion (i.e., the movement of each voice in multi-voice compositions; Bigand et al., 1996; Farbood, 2012). Across both musicians and non-musicians, variations of dynamics contributed to the emphasis of musical tension, but tonality still remained a primary influence of musical tension perception (Lenhe et al., 2013; Farbood, 2012).

Although it is clear that perceived musical tension is influenced by several musical elements, few studies have observed the role of timbre. Giordano and McAdams (2009) stated that timbre contributed to shifts between tension and resolution in large-scale musical forms. They identified the role of auditory roughness—rapid fluctuations of amplitude envelope that influence timbre. Timbral differences contributed to nontonal tension, which correlated with the sensation of roughness (Pressnitzer, McAdams, Winsberg, & Fineberg, 2000). Paraskeva and McAdams (1997) conducted one of the first approaches that observed the timbre's role on perceived musical tension in tonal contexts. Participants listened to a piano version and orchestral version of one tonal and one atonal excerpt, and rated the degree of completeness of musical phrasing with respect to tension and resolution. Participants perceived greater musical tension in orchestral versions of excerpts. Although Paraskeva and McAdams (1997) demonstrated timbre's contribution to perceived musical tension, only two timbral conditions were compared: piano timbre and orchestral timbre. The influence of multiple timbre manipulations on perceived musical tension has yet to be studied.

In the present study, we examined the role of timbre on perceived musical tension under different timbral conditions. Participants rated the musical tension of eight melodies, where each melody was played in seven timbral conditions. We hypothesized that musical tension ratings would be greater for timbres made up of even harmonics than timbres made up of odd harmonics. Timbres constructed from odd harmonics resemble woodwind-like timbres (Chowning, 1973), whereas timbres constructed from even harmonics sound more shrill. Within manipulations of odd and even harmonics, we expected greater musical tension ratings for timbral conditions in which the loudness distribution was weighted towards higher harmonics, resembling a "brighter" timbre (McAdams, 2013).

Method

Participants

Six (two males, three females, one declined to answer) graduate students from the Schulich School of Music at McGill University participated in the current study. Participation was compensated for course credit. The age of the participants spanned from 22 to 32 years. Five participants were right-handed, and one was left-handed. All participants reported having normal hearing, and one reported having perfect pitch.

Stimuli and Apparatus

Our stimuli consisted of ten melodies. Five melodies were composed to imply major mode (D, A-flat, D-flat, G, and C major). These melodies were then intervallically modified to diatonically fit into an implied minor mode (D, G-sharp, C-sharp, G, and C minor; see Figure 1). The implied harmonies followed standard Western music theory rules in form and function. Melodies were composed in common time, with a tempo of 110 bpm for ease of listening. Melodies following tempi of 100–120 bpm are standard in Western music, and some studies have shown that this is a preferred tempo range for most people, as well as for walking and finger-tapping (Gratton, Brandimonte, & Bruno, 2016; Moelants, 2002; Fraisse, 1982). The melodies comprised of whole notes, half notes, quarter notes, and eighth notes. Each melody was four measures long, resulting in a duration of 8720 ms. The range of each melody was between 13 semitones, because timbre identification worsens when the pitch range is greater than an octave (Handel & Erickson, 2001). Melodies began on pitches corresponding to frequencies between 200–440 Hz, so that pitch displacement among octaves was executed without putting upper levels of the harmonic series in an inaudible range. Intervallic content was varied, and each melody contained both stepwise motion and leaps. The melodies modulated to implied key areas that were closely related to the tonic (e.g., dominant, subdominant, relative major, relative minor, etc.); these implied modulations would have been subjective to the listener. Two of the melodies (C major and C minor) were used for the practice block, and eight were used for the experimental block (D, A-flat, D-flat, and G major, and D, G-sharp, C-sharp, and G minor).

Figure 1. Implied major mode melodies were intervallically modified to imply minor mode. An example is seen here with our D major melody (left) and D minor melody (right).

We artificially constructed the first 12 harmonics of each note for each melody using SuperCollider 3.8.0 (McCartney, 2016), which allowed for independent control of the number of harmonics and loudness distributions of the harmonics for each timbral condition. Table 1 summarizes the seven timbral conditions. We created all ten melodies under timbral condition 1, where each note of each melody was artificially constructed with the first 12 harmonics. The loudness distribution was equal across the 12 harmonics, and normalized to have a value of 1—the standard for audio in computers. The C major and C minor melodies were only used for the practice block, and did not undergo any other timbral manipulations. The following timbral manipulations apply to the remaining eight melodies. Timbral conditions 2, 3, and 4 were artificially constructed with the first six odd harmonics for each note of each melody. Loudness distributions for each of these timbral conditions were normalized to have a value of 1, but were different among these timbral conditions. Timbral condition 2 had an equal loudness distribution across the six odd harmonics. Timbral condition 3 had a loudness distribution that weighted towards the lowest harmonic that was present; the loudness of the remaining harmonics decreased exponentially with each increasing odd harmonic that was present. Timbral condition 4 had a loudness distribution that was weighted towards the highest harmonic that was present; the loudness of the remaining harmonics decreased exponentially with each decreasing odd harmonic that was present. Timbral conditions 5, 6, and 7 were constructed with the first six even harmonics for each note of the melody, in addition to the first harmonic (i.e., fundamental frequency). With the fundamental frequency absent, the melodies would sound an octave higher, because the frequency of the first even harmonic will always be twice the frequency of the fundamental frequency. Thus, the fundamental frequency was included in timbral conditions 5, 6, and 7 to compensate for the excerpts sounding an octave higher than we had intended. The loudness distributions for these three timbral conditions were normalized to have a value of 1, but were different among these timbral conditions. Each note of each melody in timbral condition 5 was constructed to have a loudness distribution that was equal across all harmonics that were present. Timbral condition 6 had a loudness distribution that was weighted towards the lowest harmonic that was present, and the loudness of the remaining harmonics decreased exponentially with each increasing harmonic that was present. Timbral condition 7 had a loudness distribution weighted towards the highest harmonic that was present; the loudness of the remaining harmonics decreased exponential with each decreasing harmonic that was present. For the experimental block, there were a total of 56 (8 melodies * 7 timbral conditions) stimuli.

The experiment was coded using JsPsych, a JavaScript library that creates and runs online experiments (de Leeuw, 2014). The results of the experiment were stored using Google Firebase, which allowed for 100 MB of storage and 50 simultaneous connections. This was enough to handle the required storage and traffic for the experiment.

Table 1. Seven timbres were created by artificially manipulating harmonics with respect to the type (odd/even), number, and loudness distribution (upper/lower). For all timbral conditions made up of even harmonics, the fundamental frequency (F_0) was also present, otherwise the melodies would sound an octave higher.

Timbral condition (TC)	*Harmonics present*	*Number of harmonics*	*Loudness distribution*
TC1	all	12	Equal across all harmonics
TC2	odd	6	Equal across all harmonics
TC3	odd	6	Weighted towards lower harmonics
TC4	odd	6	Weighted towards higher harmonics
TC5	even + F_0	7	Equal across all harmonics
TC6	even + F_0	7	Weighted towards lower harmonics
TC7	even + F_0	7	Weighted towards higher harmonics

Procedure

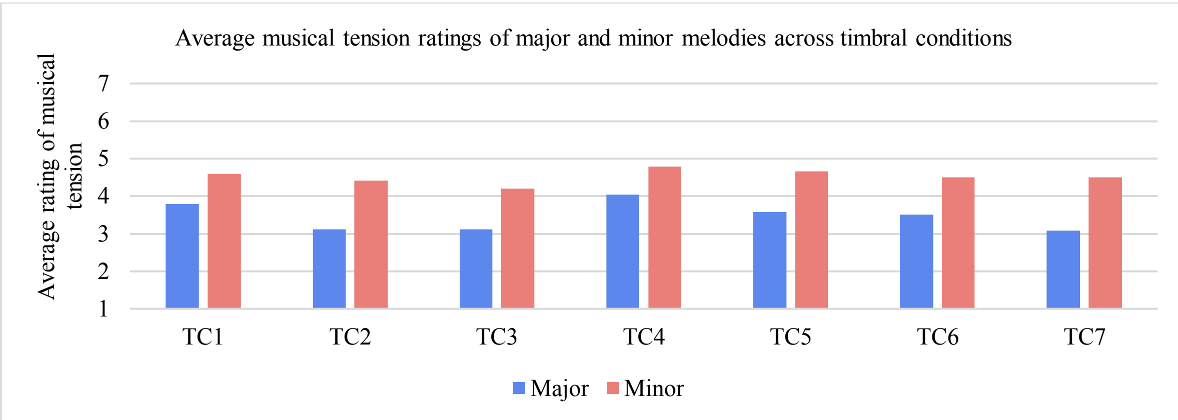
We provided the participants with a link to participate in the experiment. Participants were presented with a practice block, consisting of two trials. The participants were informed that their ratings for the practice block would not be recorded. In each trial, participants listened to the C major and C minor melodies in a randomized otder. They were instructed to listen to the melodic excerpts and rate melodic tension of the excerpts. Ratings represented the participants' perceived average musical tension of each melody, and spanned a scale from 1 to 7, where 1 corresponded to "least tension", and 7 corresponded to "most tension". Participants were instructed to indicate their ratings by using their keyboard to press the corresponding number key (1–7) that corresponded to their perceived musical tension ratings. Participants were also instructed to wait for the audio to finish before providing their ratings. The practice block ensured that participants understood the task, and gathered a sense of what the melodies would sound like. Once participants completed the practice block, they participated in the experimental block. They were informed that they will be rating melodic tension of several music excerpts. There were 56 trials in the experimental block, one for each melody stimulus. The melodies were presented to each participant in a randomized order. The instructions for the experimental block were identical to the instructions for the practice block.

Results

We calculated the mean ratings of musical tension for the major and minor melodies across all seven timbral conditions (see Figure 2). The mean musical tension ratings across all major melodies were: 3.79 (SD=1.98) for timbral condition 1, 3.13 (SD=1.57) for timbral condition 2, 3.13 (SD=1.54) for timbral condition 3, 4.04 (SD=2.12) for timbral condition 4, 3.58 (SD=1.72) for timbral condition 5, 3.50 (SD=1.56) for timbral condition 6, and 3.08 (SD=1.74) for timbral condition 7. Across all minor melodies, the mean musical tension ratings were: 4.58 (SD=1.18) for timbral condition 1, 4.42 (SD=1.53) for timbral condition 2, 4.21 (SD=1.14) for timbral condition 3, 4.79 (SD=1.47) for timbral condition 4, 4.67 (SD=1.40) for timbral condition

5, 4.50 (*SD*=1.14) for timbral condition 6, and 4.50 (*SD*=1.67) for timbral condition 7. Within each timbral condition, the mean musical tension ratings were greater for minor melodies than major melodies. We did not originally predict how the mode implied by the melodies would influence musical tension ratings; however, this result implied that musical tension was perceived differently depending on the mode of the melody.

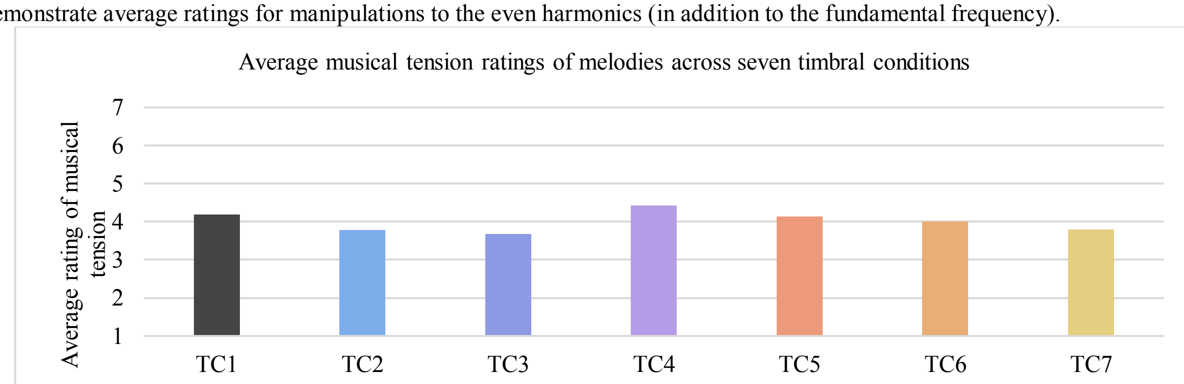
Figure 2. We grouped mean musical tension ratings according to timbral condition (TC). Blue bars represent average ratings for major melodies across the seven timbral conditions, and red bars represent average ratings for minor melodies across the seven timbral conditions.



Musical Tension Ratings Across Timbral conditions

We calculated the mean musical tension ratings for the melodies, regardless of mode, across all seven timbral conditions (see Figure 3). The mean musical tension ratings of the melodies were 4.19 (*SD*=1.66) for timbral condition 1, 3.77 (*SD*=1.67) for timbral condition 2, 3.67 (*SD*=1.45) for timbral condition 3, 4.42 (*SD*=1.84) for timbral condition 4, 4.13 (*SD*=1.65) for timbral condition 5, 4.00 (*SD*=1.44) for timbral condition 6, and 3.79 (*SD*=1.83) for timbral condition 7.

Figure 3. This graph depicts the mean musical tension ratings of melodies across all timbral conditions, regardless of the mode of the melodies. TC2, TC3, and TC4 demonstrate average ratings for manipulations to the odd harmonics. TC5, TC6, and TC7 demonstrate average ratings for manipulations to the even harmonics (in addition to the fundamental frequency).



We originally hypothesized that musical tension ratings would be greater for timbres made up of even harmonics in addition to the fundamental (e.g., timbral conditions 5, 6, and 7) than timbres made up of odd harmonics (e.g., timbral conditions 2, 3, and 4). Average musical tension ratings for timbral conditions 5, 6, and 7, however, were not that much different from that of timbral conditions 2, 3, and 4, and thus, did not align with our hypothesis. Our second hypothesis was that musical tension ratings would be greater for timbres with loudness distributions of harmonics that were more heavily weighted on higher harmonics. Although musical tension ratings were highest for melodies in timbral condition 4, musical tension ratings were not as high for melodies in timbral condition 7. Thus, these results did not entirely align with our hypothesis.

Discussion

Instead of finding differences in musical tension ratings between different timbral conditions, we found differences in musical tension ratings between major and minor modes. Participants had greater musical tension ratings for melodies implying minor mode than melodies implying major mode for every timbral condition. Since each major-minor melody pair was intervallically modified to fit within their respective mode, differences in musical tension ratings between major and minor melodies might be attributed to the different intervallic modifications we employed.

An initially surprising result was that melodies from timbral condition 1 were rated as having greater musical tension than melodies from the remaining timbral conditions, with the exception of timbral condition 4. We expected musical tension ratings for melodies of timbral condition 1 to fall towards the middle of musical tension ratings across all timbral conditions. Since timbral condition 1 was constructed with 12 harmonics, the harmonics after the seventh harmonic were a whole tone or semitone apart. In timbral conditions made up of odd harmonics or even harmonics, the distance between higher harmonics was no less than a major or minor third. Smaller distances between higher harmonics in timbral condition 1 might have contributed the perception of roughness. The sensation of auditory roughness has been previously associated with musical tension (Pressnitzer at al., 2000), and might explain why musical tension ratings were greater for melodies in timbral condition 1.

We originally expected greater musical tension ratings for timbral conditions made up of even harmonics in addition to the fundamental frequency than timbral conditions constructed with odd harmonics. We did not find differences in musical tension ratings for either of these groups of timbral conditions. We also hypothesized that musical tension ratings would be greater for timbral conditions with loudness distributions weighted towards higher harmonics, but this was also not found in our results. There may not have been enough harmonics included in our timbral conditions. With a larger number of harmonics, the distance between higher harmonics for timbral conditions constructed with even or odd harmonics would eventually approach a whole tone. Since shorter distances between higher harmonics contributed to auditory roughness (Pressnitzer et al., 2000), if we included more harmonics, musical tension ratings might have been greater for timbral conditions with loudness distributions weighted towards higher harmonics.

Having a single musical tension rating for each melody may have been a limiting factor. With a continuous slider, we could observe if changes in musical tension were attributed to timbral manipulations or perceived implied harmonies. To further tease apart the relevant contributions of implied harmonies or timbral manipulations on musical tension, we could also ask participants to indicate the implied harmony for each melody. Furthermore, we did not control for perceived loudness before running our experiment. Although the loudness distribution for all timbral conditions were normalized to have a value of 1, some timbral conditions may have been perceived as louder than others. We could have run a pilot study where individuals would match the loudness of the melodies before conducting the experiment. Additionally, the number of harmonics was not consistent for every timbral condition. To compensate for this, we should have included the same number of harmonics for each timbral condition, and placed loudness emphasis on certain harmonics depending on our desired timbral conditions. Timbre encompasses much more than the spectral components of a sound (McAdams & Giordano, 2009). Temporal and spectro-temporal attributes of timbre (McAdams & Giordano, 2009) should also be considered. It would be interesting to manipulate other timbral attributes, such as attack, decay, sustain, and release (ADSR) envelopes, and observe their influence on perceived musical tension. Since performers are specific in how they produce the sounds they want from their instrument according to the instructions in the music, manipulating ADSR envelopes might influence perceived musical tension.

The participants of the current study did not perceive differences in musical tension with respect to timbre. This implied that perception of musical tension did not directly rely on timbral changes. Given the small variability of our current participants' ratings for musical tension, we might see greater variability of ratings with more participants. Thus, we cannot fully conclude that timbre does not contribute to musical tension perception, because of the potential contributions of timbre to musical tension in a variety of domains.

For centuries, composers have written music that conveys more extremes and longevity of both emotion and harmonic tension. Famous examples include: Mozart's *Piano Concerto in A major*, K. 488; Beethoven's *Sonata in C major, "Waldstein"*, Op. 53; and Tchaikovsky's *Violin Concerto*, Op. 35, among others. There may be specific reasons why composers write certain melodies with specific musical timbres. Composers might select instrument groups based on ADSR style and harmonic series combinations; whether this is to accentuate harmonic tension or timbral tension is still a mystery. We can speculate, however, that certain instrument groups are selected to achieve a desired sound or effect in areas of a composition. This desired sound may not be achieved as well with other instrument groups. For electroacoustic composers, further research on timbre's influence on perceived musical tension can provide insight on how composers can create musical tension with synthesized sounds. The way a single instrument is played, in addition to its associated timbre, might contribute its own patterns of tension and resolution that influence perceived musical tension. A different instrument could contribute different tension and resolution patterns that influence perceived musical tension differently. A performer's awareness of their instrument's timbral traits would be desirable for composers who want to achieve specific sounds in their compositions. Additionally, a performer's awareness of their instrument's timbral capabilities in addition to their ability to manipulate their instrument's timbre is not only important in live performances; it is also important for the emerging digital and recording era. How these timbral manipulations are picked up digitally is often different than in live performances. Sound engineers typically have preferences regarding types, placements, and input adjustments of microphones based on musical instruments and their timbres, including combinations thereof in ensemble settings. Further knowledge of timbre's role on perceived musical tension could help sound engineers better hone their intuitive skills with empirical data. This knowledge also has implications for works using a combination of computer-generated and live acoustic sounds in recording and composition. Moreover, an understanding of the relationship between timbre and musical tension can inspire improvements of pre-existing instruments based on desirable and undesirable effects. Modifications can be made to instruments to achieve specific timbral qualities, which may in turn, contribute to musical tension.

Given the findings of the present study, we did not find a relationship between timbre and perceived musical tension. With the modifications described, and a larger number of participants, we could have better control for timbral parameters. There is a large gap in understanding how perceived musical tension is influenced by timbre (McAdams, 2013). Further research on finding a relationship between timbre and perceived musical tension is crucial for unpacking yet another mystery of timbre perception.

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