The Emotional Characteristics of Section String Instruments with Different Pitch and Dynamics

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ABSTRACT

Recent research has shown that different musical instrument sounds have strong emotional characteristics. It has also shown how these emotional characteristics change with different pitch and dynamics for the piano and solo bowed strings. This paper investigates how the emotional characteristics of the section bowed strings vary with pitch and dynamics, comparing and contrasting the solo and section string results. We conducted listening tests where listeners compared the section string sounds pairwise over ten emotional categories. The section and solo string results were somewhat similar overall, but with some notable differences as well. The emotional characteristics Happy, Heroic, Romantic, Comic, Calm, and Shy generally increased with pitch in an arching shape that peaked at C5 and decreased at the highest pitches. The characteristics Angry and Sad generally decreased with pitch. Scary was somewhat U-shaped and especially strong in the extreme high register. In terms of dynamics, the results showed that Happy, Heroic, Comic, Angry, and Scary were stronger for loud notes, while Romantic, Calm, Shy, and Sad were stronger for soft notes. These results provide audio engineers and musicians with possible suggestions for emphasizing various emotional characteristics of the section strings in orchestral recordings and performances.

1. INTRODUCTION

Music emotion research has flourished in recent years. In particular, various recent studies have found that different musical instruments have strong and different emotional characteristics [2-13,20,21]. The vast majority of these studies have focused on a single common pitch, usually a note just above middle C so that as many treble and bass clef instruments can be compared against one another as possible. Such an approach provides a useful point of reference when comparing the emotional characteristics of the instruments. But, it is also valuable to see how the instruments vary in their emotional characteristics with different pitch and dynamic levels. Several studies have shown that pitch and dynamic levels can change perceived aspects of the sound in speech [1,15] and isolated musical instrument tones [2].

Another approach is to try to extract the effects of different pitch and dynamic levels from musical excerpts, although it is very difficult to disentangle pitch and dynamics from the many other musical factors, especially since different listeners will focus on different musical factors. Also, musical excerpts are longer and only so many can be practically tested, making it difficult to generalize the results beyond the few that are tested. Testing isolated music instrument tones with different pitch and dynamic levels avoids these pitfalls, and allows their effects to be directly assessed isolated from any particular musical context.

In particular, in our previous work, we compared the emotional characteristics of sustaining [3,4,6,7] and non-sustaining [5,8,9] musical instruments. For both groups, the results showed distinctive emotional characteristics for each instrument. For example, among sustained instruments the trumpet was found to be relatively stronger in the emotional characteristics Happy, Heroic, and Comic than the horn, while weaker for Sad and Shy [3]. It is not that a trumpet sound cannot be Sad or Shy, but that the player will need to work harder to achieve the same levels of Sad or Shy as the horn.

We also investigated piano's emotional characteristics changed with pitch and dynamics from C1 to C8 over *piano*, *mezzo*, and *forte* dynamic levels [10,13]. Especially relevant to the current paper is our experimental finding on how the emotional characteristics of the solo bowed strings changed with pitch and dynamics [11,20]. We tested pitches ranging from C1 to C7 over and *piano* and *forte* dynamic levels. The results showed shows that the emotional characteristics Happy, Heroic, Romantic, Comic, and Calm generally increased in an arching shape with pitch that decreased at the highest pitches. The characteristics Angry and Sad generally decreased with pitch. Scary again had a U-shape that was strongest in the extreme low and high registers. Shy and Mysterious were unaffected by pitch. In terms of dynamics for the bowed strings, the result showed that Heroic, Comic, and Angry were stronger for loud notes, while Romantic, Calm, Shy, Sad, and the high register for Happy were stronger for the soft notes. Scary and Mysterious were unaffected by dynamics

Overall, the current study will help quantify the emotional effects of pitch and dynamics in the section strings and compare the result with the solo strings. Of course, the exact musical context will further modulate these general pitch and dynamic effects based on musical features such as melody, harmony, and tempo. Nevertheless, it would be helpful to quantify and visualize how the emotional characteristics of the instruments vary with pitch and dynamics to see how these trends support musical intuition, and likely uncover and expose lesser-known trends so that musicians can use them in musically useful ways. This understanding is valuable in applications such as orchestration, arrangement, blending and balancing instruments, and especially composition for film and computer games.

2. EXPERIMENT METHODOLOGY

We conducted listening tests to compare the effects of pitch and dynamics on the emotional characteristics of section string sounds. We tested section violins, violas, cellos, and double basses at three or four different pitches, and at both *forte* (loud) and *piano* (soft) dynamic levels. We compared the sounds pairwise over ten emotional categories (Happy, Heroic, Romantic, Comic, Calm, Mysterious, Shy, Angry, Scary, and Sad) to determine the effects of pitch and dynamics.

2.1 Stimuli

The experiment used section string sounds from the four main instruments in the Western bowed string family: violin (Vn), viola (Va), cello (Vc), and double bass (Cb). The section string sounds were obtained from the Prosonus sample library [16]. The sounds presented were 1.0 s in length. For each comparison, the first sound was played, followed by 0.2 s of silence, and then the second sound. Thus the total for one comparison was 2.2 s. The pitches for each instrument were as follows:

- Vn: C4, C5, C6, C7
- Va: C3, C4, C5
- Vc: C2, C3, C4, C5
- Cb: C1, C2, C3

The sounds were all C's of different octaves so as to avoid other musical intervals influencing the emotional characteristics of the sounds. Each note also had two dynamic levels, corresponding to *forte* (f) and *piano* (p)— loud and soft. Only two dynamic levels were tested, as a previous study with 3 dynamic levels, namely *forte* (f), *mezzo* (m), and *piano* (p)— loud, medium, and soft, showed that the result for *mezzo* were consistently in-between the results of *forte* and *piano* [10,13]. The total number of sounds was 28 (14 notes × 2 dynamic levels).

All sounds were recorded and sampled at 44,100 Hz with 16-bit resolution, and played back using the D/A converter with 24-bit resolution at the original sampling rate. To equalize their lengths to 1s, after the first 0.75 seconds, we simply faded the sounds to zero over the last 0.25 seconds. We verified that the sounds with fade-outs were reasonably natural and free from artifacts.

2.2 Test Procedure

28 subjects were hired to take the listening test. All subjects were fluent in English. They were all undergraduate students at the Hong Kong University of Science and Technology where all courses are taught in English.

The subjects were seated in a quiet room with 39dB SPL background noise level. The noise level was further reduced with headphones. Sound signals were presented through Sony MDR-7506 headphones. The volume on all computers were calibrated manually so that the C4 *forte* violin tone sounded at the same moderate loudness level as judged by the authors.

The subjects were provided with an instruction sheet containing definitions of the ten emotional categories from the Cambridge Academic Content Dictionary[17].

Every subject made pairwise comparisons on a computer among all 28 combinations of instruments, pitches, and dynamics for each emotional category. During each trial, subjects heard a pair of sounds of different instruments, pitches, and/or dynamics and were prompted to choose the sound that represented the given emotional category more strongly. Each trial was a single paired comparison requiring minimal memory from the subjects. Paired comparison is a simple decision, and is easier than absolute rating.

Each combination of sounds was presented once for each emotional category, and the listening test totaled $28C2$ combinations × 10 emotional categories = 3780 trials. For each emotional category, the overall trial presentation order was randomized (i.e., all the Happy comparisons were first in a random order, then all the Heroic comparisons were second, and so on).

Altogether the listening test took about 2–3 hours. It was conducted over several 30 minute sessions to help minimize listener fatigue and maintain consistency. The listeners were given a 5 minute break every 30 minutes.

3. RESULTS

We ranked the sounds by the number of positive votes received for each emotional category, deriving scale values using the Bradley–Terry–Luce (BTL) statistical model [18,19]. The BTL values for each emotional category sum to 1. The BTL value given to a sound is the probability that listeners will choose that sound when considering a given emotional category. For example, if all 28 sounds (14 notes × 2 dynamic levels) were considered equally Happy, the BTL scale values would be $1/28 \approx 0.0357$. The corresponding 95% confidence intervals were derived using Bradley's method [19]. Fig. 1 shows graphs for the BTL scale values and the corresponding 95% confidence intervals for each emotional category and instrument of the section strings.

The individual instrument lines are similar, and together outline an overall trend for the section bowed strings for each emotional characteristic (e.g., the *forte* Happy lines). There are a few distinctive outliers such as the *piano* cello at C5 for Calm.

The emotional categories in Fig. 1 fall into four general shapes across the pitch range. Six of the categories had an arched shape that peaked at C5, namely Happy, Heroic, Romantic, Comic, Calm, and Shy. Two of the categories generally decreased with pitch: Angry and Sad. Scary had an asymmetric U-shape that was especially strong at the highest pitches, a result which indirectly agrees with Krumhansl's finding that large variations in pitch resulted in significantly higher ratings for Fear [14]. Mysterious was uniquely flat.

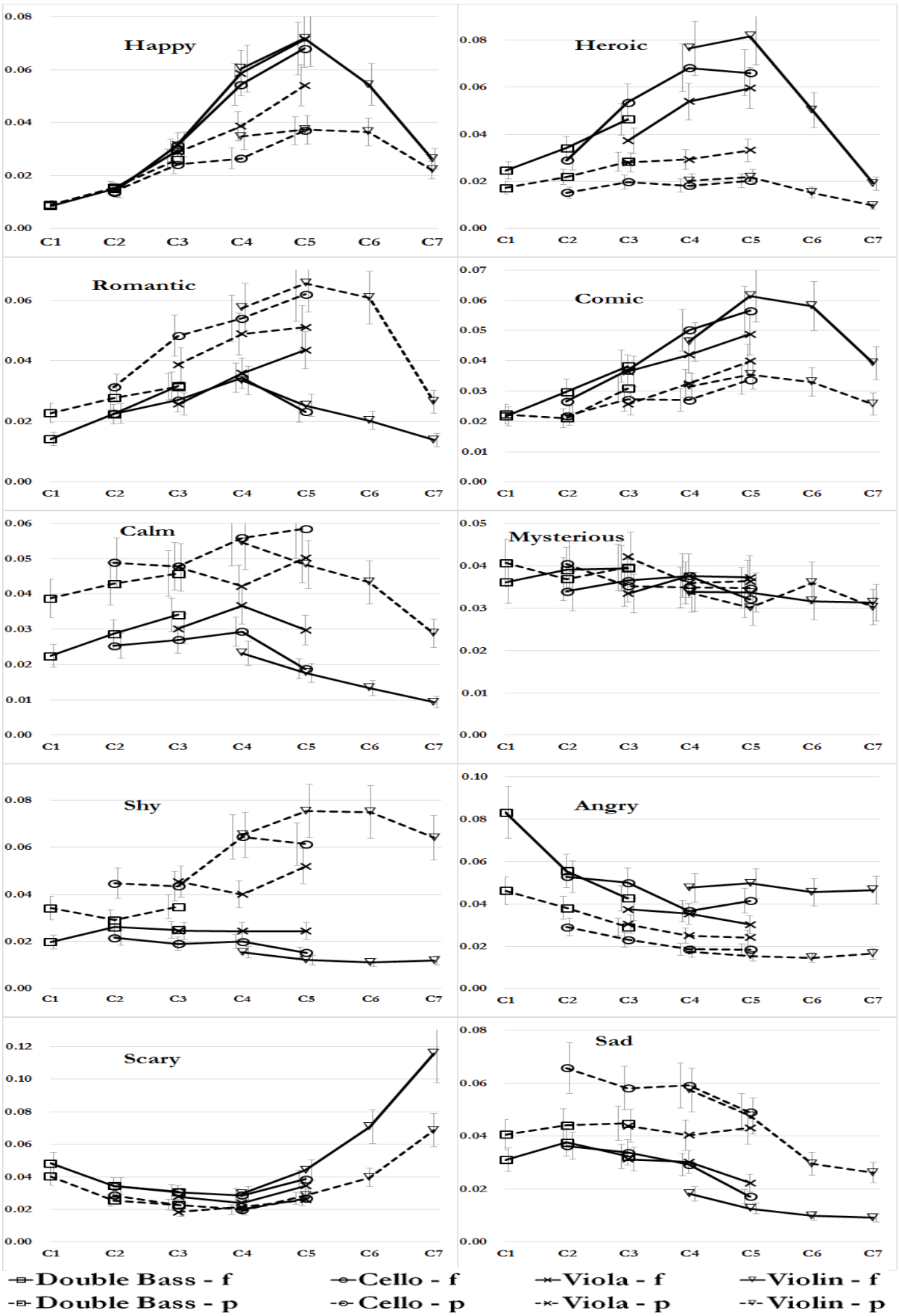

Fig. 1: Emotional characteristics of section string sounds based on the BTL scale values and the corresponding 95% confidence intervals.

Regarding dynamics, five categories were stronger for loud notes, namely Happy, Heroic, Comic, Angry, and Scary. The emotional categories Romantic, Calm, Shy, and Sad were stronger for soft notes. For Mysterious, loud and soft notes were about the same.

3.1 The Effects of Pitch and Dynamics

The curves for most of the categories in Fig. 1 showed clear trends. For example, for Happy, there was a strong arch for *forte* and a gentler arch for *piano*.

To quantify these trends, we wanted to determine whether the effects of pitch and dynamics were significant for the section string tones. An ANOVA analysis is the usual way to accomplish this, but ANOVA requires independent variables. For the section strings, pitch and dynamics are independent, but instrument is not since for example the violin only ranges from C4 to C7 and does not include tones from C1 to C3. Alternatively, we can treat the section string family as a single instrument for the purposes of this analysis, and select representative tones for each pitch. We constructed our "most representative" section strings (double bass for C1, cello for C2-C4, violin for C5-C7) and "less common" section string (double bass for C1-C2, viola for C3-C5, and violin for C6-C7). We can then run ANOVA on both representatives of the section strings and compare the results.

Table 1 shows the ANOVA results. The most representative and less common instruments were in agreement. This means that the violas and double basses had about the same collective effects on pitch and dynamics as the violins and cellos. In particular, the effects of pitch and dynamics were both significant for eight of the ten categories at the $p<0.05$ level. Mysterious was flat and noisy, and not significant for either pitch or dynamics. Shy was not significant for pitch, largely because it increased from C2 to C5 for soft tones, while slightly decreasing for loud tones. Happy was not significant for dynamics, largely because C1 and C2 were identical for loud and soft tones, and the gap was also narrow for C3 and C7.

	Most Representative		*Less Common*	
	Pitch	Dynamics	Pitch	Dynamics
Happy	0.000	0.073	0.000	0.144
Heroic	0.000	0.000	0.000	0.000
Sad	0.000	0.000	0.001	0.000
Comic	0.021	0.001	0.037	0.001
Scary	0.000	0.014	0.000	0.002
Shy	0.369	0.000	0.286	0.000
Romantic	0.000	0.000	0.000	0.000
Mysterious	0.653	0.841	0.663	0.566
Angry	0.000	0.000	0.000	0.000
Calm	0.000	0.000	0.000	0.000

Table 1: p-values from the two-way ANOVA for the effects of pitch and dynamics. Values that were significant ($p < 0.05$) are shown in bold and shaded in grey.

3.2 Differences Between the Individual Instruments

We identified differences between section string instruments by calculating BTL differences between instruments at the same pitch and dynamic level. Most of the 200 possible pairs (10 shared pitches between the 4 instruments × 2 dynamic levels × 10 emotional categories) were not significantly different. However, there were a number of exceptions. Table 2 lists the biggest BTL differences ordered from largest to smallest. In general, the biggest BTL differences for the section strings were about half the value of the solo strings [32,40]. Out of the 20 entries in Table 2, 15 were C4 or C5.

Emotion Categories	Instruments	Sound	ΔBTL
Shy	Vn>Va	C4p	0.0253
Shy	Vc>Va	C4p	0.0245
Shy	Vn>Va	C5p	0.0235
Heroic	Vn>Va	C4f	0.0226
Heroic	Vn>Va	C5f	0.0220
Sad	Vc>Cb	C2p	0.0216
Romantic	Va>Vc	C5f	0.0204
Angry	Vn>Va	C5f	0.0195
Sad	Vc>Va	C4p	0.0187
Romantic	Va>Vn	C5f	0.0183
Happy	Va>Vc	C5p	0.0171
Sad	Vn>Va	C4p	0.0170
Romantic	Vc>Cb	C3p	0.0169
Happy	Va>Vn	C5p	0.0167
Heroic	Vc>Va	C3f	0.0163
Shy	Vc>Cb	C2p	0.0156
Heroic	Vn>Vc	C5f	0.0155
Romantic	Vn>Va	C5p	0.0146
Heroic	Vc>Va	C4f	0.0143
Sad	Vc>Va	C3p	0.0142

Table 2: Biggest BTL differences between different bowed string instruments at the same pitch and dynamic level, ordered from largest to smallest.

We will describe a few examples of the biggest differences. For C4 and C5 *piano* notes, the violin was regarded as more Shy than the viola. Similarly, for C4 and C5 *forte* notes, the violin was considered more Heroic than the viola. The cello was ranked much more Shy and Sad than the double bass at C2. In general, the viola was often in the middle in Fig. 2, lower than the violin and cello which outline the topmost curves, and higher than the outline of the bottom curve (e.g., especially for Heroic, Romantic, Comic, Calm, Shy, and Angry). This indicates that the viola's range of emotional characteristics was more compressed than the violin and cello.

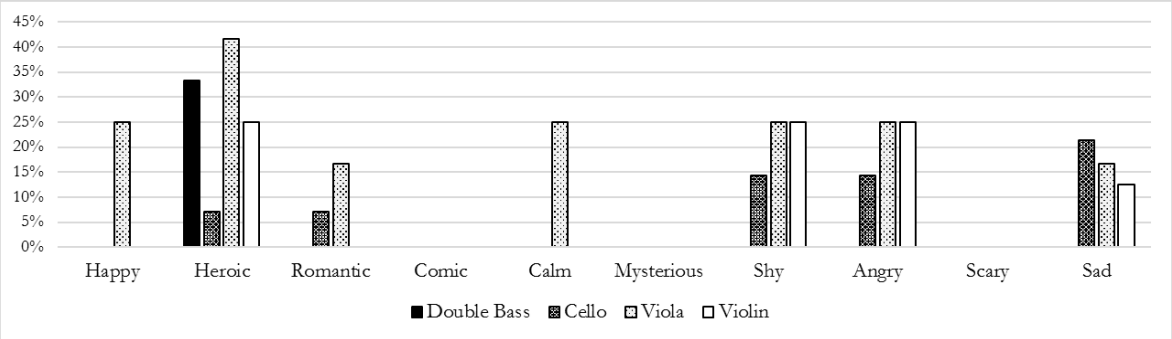

Fig. 2: Percentage of cases where each instrument was significantly greater than other instruments at the same pitch and dynamic level.

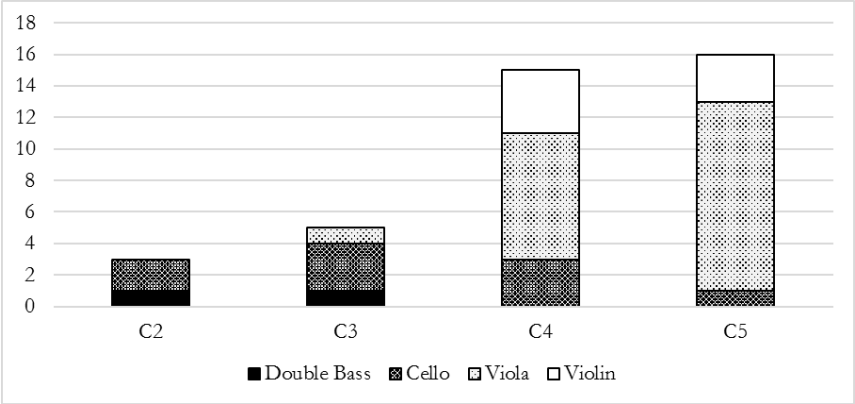

Fig. 3: Total number of cases that an instrument was significantly greater than another instrument for each pitch.

As an alternative, more general perspective, Fig. 2 shows the percentage of cases where each instrument was significantly greater than other instruments for each category at the same pitch and dynamic level. So, for example the section violas were significantly greater than other instruments 25% of the time for Happy and Calm.

Fig. 3 shows the total number of cases that an instrument was significantly greater than another instrument for each pitch. It only includes C2 to C5 since only the double bass is at C1 and only the violin is at C6 and C7. The vast majority of cases were equally split between C4 and C5. This indicates that the region around C4 and C5 is a hotspot for differentiating the individual section string instruments, especially between the violas and the other instruments.

4. DISCUSSION

Eight out of ten emotional categories were significantly effected by pitch. Happy, Heroic, Romantic, Comic, and Calm increased with pitch up to C5, then decreased. Angry and Sad generally decreased with pitch. Scary was somewhat U-shape and strongest in the highest register. Mysterious and Shy were unaffected by pitch. Eight out of ten emotional categories were significantly effected by dynamics. Heroic, Comic, Angry, and Scary were stronger for loud notes. Romantic, Calm, Shy, and Sad were stronger for soft notes. Mysterious, and Happy were unaffected by dynamics.

The results showed that pitch generally had a similar effect on emotional categories with similar overall Valence. The positive characteristics Happy, Heroic, Romantic, Comic, and Calm had similar shapes in Fig. 1 (increasing up to C5, then decreasing), while the negative characteristics Angry and Sad were decreasing. Scary was an outlier, decreasing slightly with pitch like Angry and Sad in the lowest register, but with a strong upward trend in the high register. The more neutral categories Mysterious and Shy were unaffected by pitch.

Dynamics had a similar effect on most emotional categories with similar overall Arousal. The energetic characteristics Happy, Heroic, Comic, Angry, and Scary were strongest for loud notes, while the lower-energy characteristics Calm, Romantic, Shy, and Sad were strongest for soft notes. The more neutral category Mysterious was unaffected by dynamics.

The BTL curves for the solo and section strings were basically similar (compare Fig. 1 with Fig. 3 in [11]). Overall, for pitch, nine of ten emotional characteristics basically agreed in their overall trend. Shy was most different with a flat shape for the solo strings and a mostly increasing arching shape for the section strings. For Scary, though both solo and section strings were U-Shaped with pitch, the results were stronger in the lower register for solo strings and the higher register for section strings. For dynamics, the similarities were also striking, and 9 of 10

emotional categories basically agreed. Happy was the biggest difference. Soft notes were considered less Happy for section strings compared to loud notes, especially for C6 and C7, while soft notes were considered more Happy for solo strings. It is not surprising Heroic, Comic, and Angry would be loud for both solo and section strings, while Calm, Shy, and Sad would be soft. However, it is interesting that Mysterious and Scary would be unaffected or relatively less affected by dynamics in both solo and section strings.

We suspect that the agreement in dynamics is probably fairly instrument-independent since categories such as Shy and Calm are inherently soft by nature. Happy is an interesting possible exception since it is could be interpreted as both excitedly-Happy or serenely-Happy. Pitch is almost certainly more instrument-dependent, since each instrument has its own particular pitch range and timbre. Further work with other instruments can help put these ideas on more solid footing.

These results confirm some existing common practices for emotion emphasis in composition and arrangement (e.g., using loud, very high violins for Scary passages), and expose some less well known ones such as the sweet spot at C5 for the emotional categories Happy, Heroic, Romantic, Comic, Calm, and Shy.

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