The Emotional Characteristics of Brass Musical 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 bowed strings. This work differentiates the distinctive emotional characters of the brass instruments, and investigate how pitch and dynamics influence their characters. We conducted listening tests where listeners compared the brass instrument sounds pairwise over ten emotional categories. The emotional characteristics Happy increased with pitch. Heroic, Romantic, and Comic generally increased with pitch in an arching shape that peaked at C5 and decreased at the highest pitches. Calm, Mysterious, and Shy are also in arching shape but peaked at C3. Angry and Scary was somewhat U-shaped and especially strong in the extreme high register. Sad decreased with pitch. In terms of dynamics, the results showed that Heroic, Comic, Angry, and Scary were stronger for loud notes, while Romantic, Calm, Mysterious, Shy, and Sad were stronger for soft notes. These results help orchestrators and composers make the jump from knowing a particular pitch is technically possible on an instrument, to understanding how its pitch register shapes its emotional character.

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 [1-15]. 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 [16,17] and isolated musical instrument tones [1].

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 not 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 [2,3,5,6] and non-sustaining [4,7,8] 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 [2]. 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 [9,12]. Especially relevant to the current paper is our experimental finding on how the emotional characteristics of the bowed strings changed with pitch and dynamics [10,13,15]. We tested pitches ranging from C1 to C7 over and *piano* and *forte* dynamic levels. The results showed 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 Brass instruments. 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 individual brass instrument sounds. We tested the trumpet, horn, trombone, and tuba 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 sounds from the four main instruments in the brass family: trumpet, horn, trombone, and tuba. The sounds were obtained from the Prosonus sample library [18]. The sounds presented were 0.9 s in length, with a short linear fadeout release. 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 s. The pitches for each instrument were as follows:

- Trumpet: C4, C5, C6
- Horn: C2, C3, C4, C5
- Trombone: C2, C3, C4, C5
- Tuba: C1, C2, C3, C4

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. The total number of sounds was 30 (15 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

66 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* Trumpet 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[19].

Every subject made pairwise comparisons on a computer among all 30 combinations of instruments, pitches, and dynamics for five emotional categories. For each emotional category, there were 33 subjects' response. 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 $30C2$ combinations × 5 emotional categories = 2175 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 hours. It was conducted over several 15 minute sessions to help minimize listener fatigue and maintain consistency.

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 [20,21]. 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 30 sounds (15 notes × 2 dynamic levels) were considered equally Happy, the BTL scale values would be $1/30 \approx 0.0333$. The corresponding 95% confidence intervals were derived using Bradley's method [21]. Fig. 1 shows graphs for the BTL scale values and the corresponding 95% confidence intervals for each emotional category and instrument of the brass.

The individual instrument lines are similar, and together outline an overall trend for the brass for each emotional

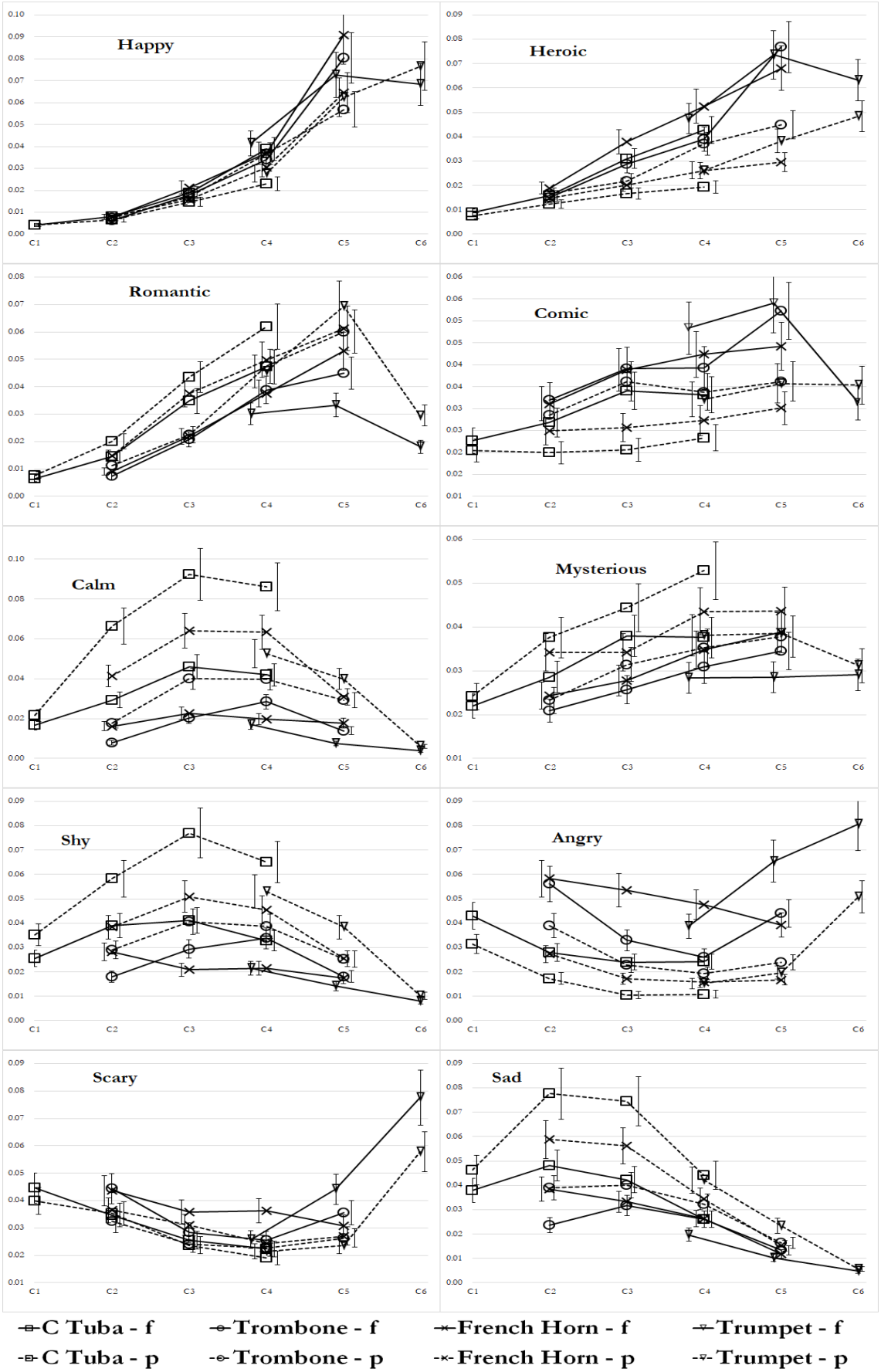

Fig. 1: Emotional characteristics of Brass instrument sounds based on the BTL scale values and the corresponding 95% confidence intervals.

characteristic (e.g., the *forte* Heroic lines). There are a few distinctive outliers such as the *piano* Tuba at C4 for Mysterious.

The emotional categories in Fig. 1 fall into five general shapes across the pitch range. Happy increased with pitch. Three of the categories had an arched shape that peaked at C5, namely, Heroic, Romantic, and Comic. Three of the categories also had arched shape peaked at C3: Calm, Mysterious, and Shy. Two of the categories had an asymmetric U-shape that was especially strong at the highest pitches, namely Angry and Scary, a result which indirectly agrees with Krumhansl's finding that large variations in pitch resulted in significantly higher ratings for Fear [22]. Sad decreased with pitch.

Regarding dynamics, four categories were stronger for loud notes, namely Heroic, Comic, Angry, and Scary. The emotional Romantic, Calm, Mysterious, Shy, and Sad were stronger for soft notes. For Happy, 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. 2 showed clear trends. For example, for Calm, there was a strongly curved arch for piano and a gentler arch for forte. To quantify these trends, we wanted to determine whether the effects of pitch and dynamics were significant for the brass instruments. An ANOVA analysis is the usual way to accomplish this, but ANOVA requires independent variables. For the brass, pitch and dynamics are independent, but instrument is not since, for example, the trumpet only ranges from C4 to C6 and does not include tones from C1 to C3. For the purposes of this analysis, we decided to separate the brass family into two groups by the shape of their bore, namely the conical instruments (horn and tuba) and the cylindrical instruments (trumpet and trombone). Using this idea, we constructed a general conical brass instrument using the tuba for C1-C2 and the horn for C3-C5 (see Fig. 3). We also constructed a cylindrical brass instrument consisting of the trombone for C2-C4 and the trumpet for C5-C6 (see Fig. 4). We can then run ANOVA on the conical and cylindrical brass instruments to determine whether the effects of pitch and dynamics were significant.

Table 1 shows the ANOVA results. The conical and cylindrical instruments were mostly in agreement in regards to the effects of pitch and dynamics (except for Happy, Comic, and Scary). In particular, the effects of pitch and dynamics were both significant for eight out of the ten emotional categories at the $p<0.05$ level. Mysterious was not significant for pitch, largely because the trend was relatively flat.

	Most Representative		*Less Common*	
	Pitch	Dynamics	Pitch	Dynamics
Happy	**0.000**	**0.004**	**0.000**	0.708
Heroic	**0.000**	**0.000**	**0.000**	**0.001**
Sad	**0.000**	**0.000**	**0.000**	**0.000**
Comic	**0.013**	**0.003**	0.277	0.148
Scary	0.247	0.142	**0.000**	**0.002**
Shy	**0.000**	**0.000**	**0.000**	**0.000**
Romantic	**0.000**	**0.006**	**0.000**	**0.000**
Mysterious	0.064	**0.006**	0.254	**0.035**
Angry	**0.040**	**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 brass instruments by calculating BTL differences between instruments at the same pitch and dynamic levels. Most of the 300 possible pairs (15 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. Out of the twenty entries in Table 2, 15 were at C2 or C3, and nine were for the category Calm.

Emotion Categories	Instruments	Sound	ΔBTL
Calm	T>Tb	C3p	0.052
Calm	T>Tb	C2p	0.049
Calm	T>Tb	C4p	0.046
Sad	T>Tb	C2p	0.039
Shy	T>Tb	C3p	0.036
Sad	T>Tb	C3p	0.034
Calm	T>Tp	C4p	0.033
Angry	Hn>T	C2f	0.030
Angry	Hn>T	C3f	0.029
Shy	T>Tb	C2p	0.029
Calm	T>Hn	C3p	0.028
Angry	Tb>T	C2f	0.028
Shy	T>Tb	C4p	0.026
Angry	Tp>Hn	C5f	0.026
Shy	T>Hn	C3p	0.026
Calm	T>Tb	C3f	0.026
Calm	T>Hn	C2p	0.025
Calm	T>Tp	C4f	0.025
Sad	T>Tb	C2f	0.025
Calm	Hn>Tb	C3p	0.024

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

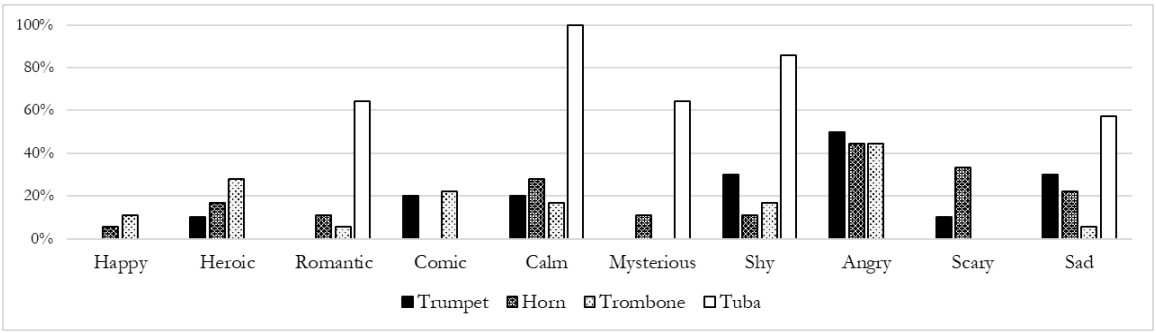

Fig. 2: Percentage of cases where each instrument was significantly greater than other instruments at the same pitch and dynamic level.

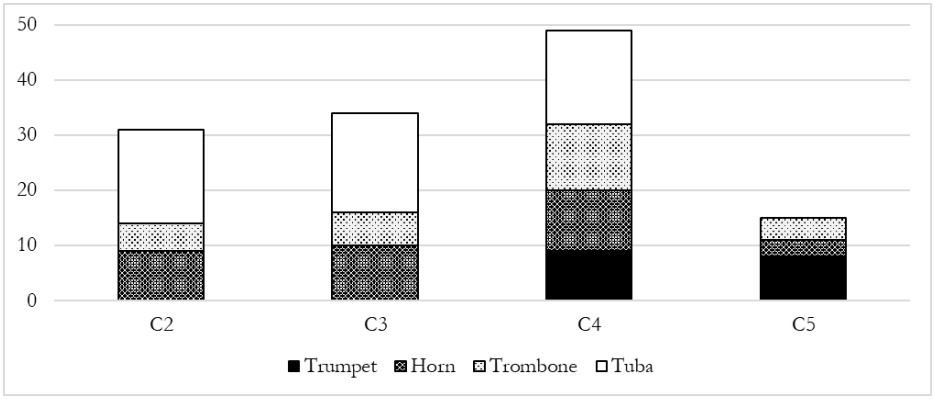

Fig. 3: Total number of cases that an instrument was significantly greater than other instruments for each pitch.

We will describe a few general trends in the biggest BTL differences. For C2, C3, and C4 piano notes, the tuba was regarded as more Calm, Shy, and Sad than the trombone. Similarly, for C2 and C3 forte notes, the horn was considered more Angry than the tuba.

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 tuba was significantly greater than other instruments 100% of the time for Calm, about 80% of time for Shy.

Fig. 3 shows the total number of cases that an instrument was significantly greater than another instrument for each pitch. Fig. 3 ranges from C2 to C5 since only the tuba includes C1 and only the trumpet includes C6. Nearly half of cases were at C4. This indicates that the C4 is a hotspot for differentiating the individual brass instruments, especially between the trombone and the other instruments.

4. DISCUSSION

Nine out of ten emotional categories were effected by pitch. Happy increased with pitch. Heroic, Romantic, and Comic increased with pitch up to C5, then decreased. Calm, Mysterious, and Shy increased with pitch up to C3, then decreased. Angry and Scary was somewhat U-shape and strongest in the highest register. Sad generally decreased with pitch. Nine out of ten emotional categories were effected by dynamics. Heroic, Comic, Angry, and Scary were stronger for loud notes. Romantic, Calm, Mysterious, Shy, and Sad were stronger for soft notes. 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 Heroic, Romantic, Comic, and Calm had similar shapes in Fig. 1 (increasing up to middle register, then decreasing), while the negative characteristic Sad were decreasing. Angry and Scary were outliers, decreasing slightly with pitch like Sad in the lowest register, but with a strong upward trend in the high register.

Dynamics had a similar effect on most emotional categories with similar overall Arousal. The energetic characteristics 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.

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 Trumpet for Scary passages), and expose some less well known ones such as the sweet spot at middle register for the emotional categories Heroic, Romantic, Comic, Calm, Mysterious, and Shy.

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