Spectral characteristics of the baroque trumpet: a case study

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The baroque trumpet like many reconstructed or original historical instruments is very difficult to play compared to its modern day equivalent. It is commonly accepted that historically informed performances need a specialist baroque trumpeter performing on a specialist instrument in order to achieve the desired sound. Particularly, there are certain timbral characteristics and expectations concerning the range of dynamics employed that are highlighted by today's early music conductors and players as being unique to and expected of the baroque trumpet. An opportunity arose to record a world-renowned baroque trumpeter playing original trumpets from 1780, 1788, 1912 and 1967 in the fully (6-sided) acoustic anechoic chamber at the University of York. Due to his strong instinct as a player that the mouthpiece is the most significant timbral characteristic of the instrument, performances on the later two trumpets were recorded using two different mouthpieces. The spectral characteristics of each of the instruments and the impact of changing the mouthpiece are analysed in terms of the spectral correlates of audible differences integral to the sound quality of each.

1 Introduction

Whilst instruments and instrumentalists took the lead in the early music movement of the 1950 and 60s ahead of the singing voice, paving the way for exploration of playing styles and new performance conventions, the trumpet was 'the last remaining instrument of the baroque orchestra to be revived' [1]. The playing of baroque music by 'period orchestras', that is orchestras formed of musicians performing on historical or reconstruction instruments, is now firmly ensconced in modern performance convention.

The baroque trumpet is notoriously difficult to play, the technicalities of which are explored by Downey [2], and could be a contributory factor to the delay in its revival. As a result there are only a relatively small number of professional baroque trumpeters. When historical performances do take place it is common for 'baroque trumpeters' to use a modern baroque trumpet, which has up to four holes in the side (a modern adjustment) to aid with tuning. The natural trumpet produces a unique sound, and, when played well, is a desired and essential component of many directors' baroque orchestras**.** With the introduction of 'crooking' mechanisms (e.g. slides or piston or rotary valves) and the shortening of the air column in the 1720s, the trumpet altered dramatically. These alterations served the purpose of improving the ease of playing notes in-tune with an orchestra and increasing the playing potential of the instrument in terms of notes available. These adaptations dramatically altered the quality of the sound produced which remains a subject of strong opinion:

> *This foreshortening effect has been the curse of the trumpet from the time of Bach to the present day. What is gained by way of accuracy (inasmuch as the desired notes on an instrument with a shorter bore are its more easily played and wider spaced lower harmonics), is lost by way of timbre* [3]

One of the most common dislikes of modern day baroque trumpeters is the 'loudness' of the modern trumpet and the association of the trumpet with loud dynamics, 'One most unfortunate side-effect of mechanization has been the increased dynamic level resulting from too much security of pitch accuracy' [1]. Accomplished players of the baroque trumpet are adept at altering the playing technique appropriate to their musical surroundings (e.g. a small baroque ensemble, a solos vocal line etc.). The technique of playing in the upper register of the natural trumpet often used when performing with such musical forces, known as *clarion* or *clarino* playing, deteriorated as the instrument evolved alongside other performance conventions. Recent research into modern trumpets has confirmed the large variation in sound quality produced between different performers and when altering dynamics [4].

Crispian Steele-Perkins is a world-renowned baroque trumpeter based in England with a large collection of historical trumpets. Anechoic recordings were made of him playing a selection of his instruments for the *openair* project at the University of York (www.openairlib.net) which is producing a catalogue of anechoic recordings of professional instrumentalists for use by researchers. Based on his experiences as a player he believes that the mouthpiece contributes perhaps more to the timbre of the sound than the instrument itself. Steele-Perkins's instincts tie in with those of Smithers, another baroque trumpeter who also highlights the importance of the mouthpiece to the sound of the instrument, 'As in the relationship of the violin and bow, the trumpet and mouthpiece are one indivisible instrument' [3]. A study of the acoustic properties of two baroque trumpets by Halfpenny also places importance on the mouthpiece as strongly affecting the sound quality of the trumpet [5].

The purpose of this study was to consider the acoustic output from the instruments recorded and to note any characteristic differences that might contribute to their auditory distinction.

2 Methodology

The recording took place in the fully (6-sided, measuring 5m x 5m x 5m externally) anechoic chamber at the Audio Lab, the University of York. One AKG C414 XLS omnidirectional microphone was placed a meter from the end of the bell of the trumpet directly in front of the player and another identical microphone was placed one meter from the end of the bell of the trumpet at a 20 degree angle from the direction of playing. A solid state Tascam DR 680 recorder was used to record the input from both microphones. 'A' weighted calibration tones were taken for each trumpet using a dB SPL meter placed next to the direct microphone.

Crispian Steele-Perkins performed several tasks on four instruments that demonstrated the range and potential notes available on each instrument. Excerpts from several pieces of music that were relevant to the period and style of playing for each instrument were also performed. Three articulations were recorded on each instrument (slurred, tongued and slurred-tongued) apart from the modern trumpet (T1967), for which slurred-tongued was omitted as the player didn't feel it was appropriate for the instrument. The pieces played sometimes differed on the same instrument between articulations to maintain idiosyncrasy with each trumpet's style. The two most modern instruments of the four were recorded twice with different mouthpieces each time. See Table 1 for descriptions of the instruments.

Table 1 : Trumpet information including make and date

Trumpet reference	Trumpet type	Date	Maker
T1780	Natural Trumpet	c.1780-1790	Kohler, London
Original inc. mouthpiece. Evidence that this trumpet was played at Drury Lane.			
T1888	Handel Trumpet	1888	Hawkes
Made for Walter Morrow, copied from a trumpet played in London by Julius Kosleck in a performance of B Minor Mass. 2 Valves. Played with a Hawkes mouthpiece approx 1915.			
T1912	Pocket Cornet	1912	A. Turtle, Manchester
Also known as the Preacher's cornet. 3 valves. Played on Hawkes mouthpiece approx. 1915 and Modern American Mouthpiece			
T1967	Piccolo Trumpet	1967	Selmer, Paris
4 valves used for baroque repertoire by modern players. Played with a Modern Mouthpiece and Cornet Mouthpiece.			

The following pieces were recorded: Fanfare (T1780); Piece 1: Trumpet Voluntary (T1780); Piece 2: Trumpets of Sound (T1888); Piece 3: Serenade, J. Clarke (T1888); Piece 4: Improvisation (T1888); Piece 5: Pretty Jane, H Bishop (T1912);Piece 6: Rule Brittania, T. Arne (T1912); Piece 7:Trumpet Concerto, J.Haydn (T1912); Piece 8: Te Deum, Charpentier (1967).

3 Results and discussion

3.1 Long Term Average Spectra

Long Term Average Spectra (LTAS) were created for the pieces performed on each trumpet at different articulations and are shown in Figure 1. All acoustic analysis was carried out using PRAAT (http://www.fon.hum.uva.nl/praat/).

The overall shapes of the LTAS curves for the four trumpets are similar in that after a peak or peaks in the lower frequencies of the spectrum there is a roughly even decay in the amplitude of the harmonics to about 10kHz. T1780 produces the most rapid decay in harmonics reaching -70 at 10kHz. The other trumpets have an overall decay of -60dB at 10kHz depending on the articulation (when slurring T1912 decays to -70 by 10kHz).

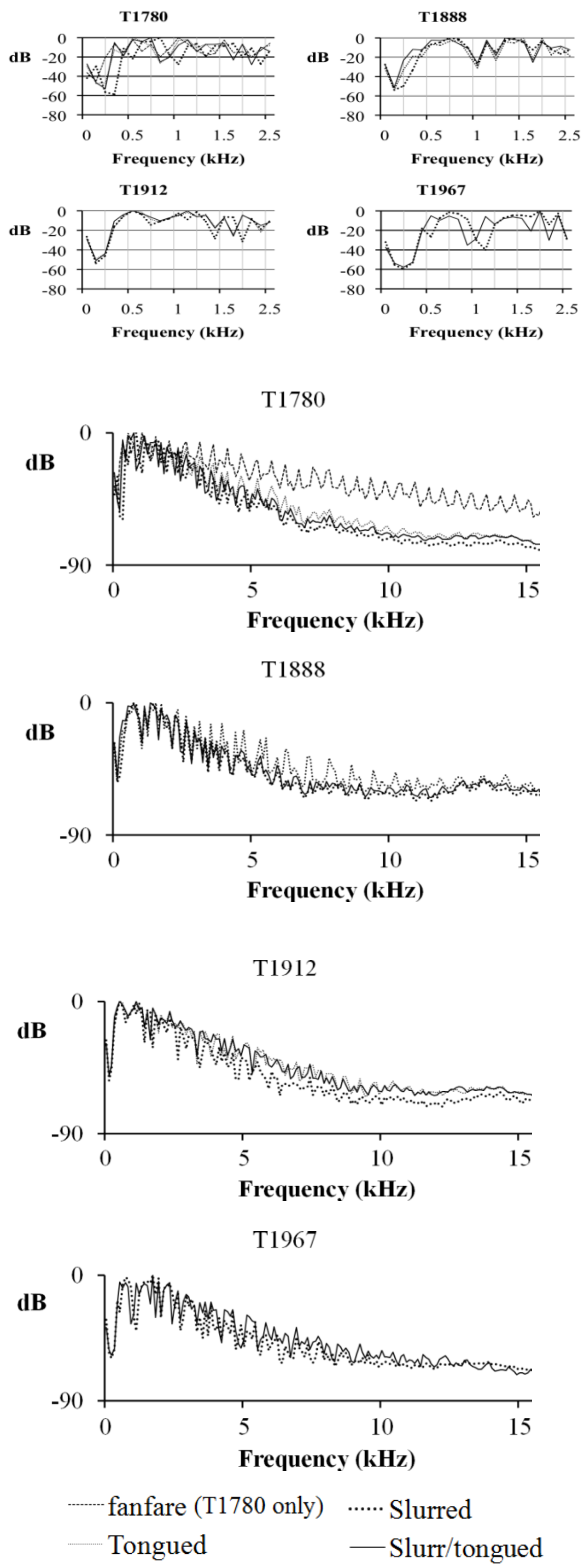

Figure 1: LTAS of all trumpets performing excerpts from pieces in different articulations to 2.5kHz (top) and 15kHz (bottom)

In addition to spectral slope, there are other subtle differences observable in the LTAS which could contribute to the stark changes in sound production between the instruments. The relationship between the energy in the low frequency harmonics and characteristics in the spectral envelope above 10kHz alter slightly between trumpet and articulation. T1780 was the only trumpet for which a fanfare was recorded and produces a drastically less steep spectral slope to the other pieces played using all articulations on all trumpets, although the equal decay in harmonics characteristic of T1780 remains. The average intensity of the pieces played on T1780 including the fanfare is very similar with only a 1dB difference, suggesting that an articulatory factor is having an effect on the slope rather than the fanfare being playing at a higher intensity causing the slope to decrease.

The initial peak in the spectral envelope for T1780 appears at approximately 700 - 800Hz for all articulations and is the strongest peak in the spectrum: the amplitude of all harmonics decaying (although by low dB values) at frequencies above this peak. All the other trumpets, however, produce a perceivable double peak early in the spectrum to approximately 1.5kHz for T1888 and 1.1kHz for T1912. For T1912 the lack of a considerable 'dip' in the spectral envelope before 1.2kHz reduces the effect of a second peak, creating maintenance of energy at higher frequencies in the spectrum than T1780. The LTAS for T1967 reveals the second peak in the spectral envelope is approximately 5dB higher than the first and at a higher frequency than for the other trumpets at 1.7kHz. A considerable dip is also apparent at 1kHz for T1967 further enhancing the significance of the second peak.

Above 10kHz an additional 'bump' is apparent in the LTAS of most trumpets in most conditions due to a gradual increase and decrease in energy between 10kHz – 15kHz. This is most pronounced for T1888 then T1912 respectively and for both these trumpets this acoustic trait appears in all articulations. This characteristic is less apparent in T1780, where rather than an increase in the relative energy, above 10kHz the amplitude stabilises before decreasing again at 15kHz. It is interesting to note that this is not apparent in the LTAS of the fanfare. A small increase in energy is observable in the slurred LTAS of T1967, but not apparent in the tongued version, where the spectral envelope continues to slope downwards, although at a slower rate. For all trumpets this trend is more pronounced the less articulated the playing (i.e. slurred pieces produced most noticeable increase in energy 10kHz – 15kHz).

The earlier trumpets produce greater differences in LTAS between articulations than the later two trumpets. Particularly, the tongued articulation creates very strong peaks across the spectrum compared to the other conditions in T1780 and particularly T1888**.** Once again it is important to note the striking change in LTAS with the fanfare for T1780, which was mentioned above, which could be due to a change in articulatory condition. A fanfare was not played on the other instruments so direct comparison is not possible, however, the four different articulations for this trumpet do seem to demonstrate potential for the considerable contrasts in sound quality that the players believe distinguish the instrument from its modern day counterparts.

3.2 Onsets

Whilst the LTAS illustrate some of the acoustic differences that likely represent the differences that can be heard between the instruments, another important aspect of perception of timbre is known to be the onset of tones [6], which are not represented in an LTAS due to the averaging which takes place.

Figure 2 shows spectrograms of the four trumpets when played with tongued articulation. As expected the onset is 'clean' for all trumpets in that the energy appears across the frequencies of the spectrograms almost simultaneously. However, closer inspection shows that there are subtle differences between the onset characteristics of the trumpets. The onset 'line' in the spectrogram of T1780 is very sharp across all frequencies, although between 2 – 4kHz the relative energy does increase throughout the first third of the note. In contrast the spectrograms for T1912 and particularly T1967, although producing clear onsets, present a delay after the initial onset before true harmonics enter across the spectrum. It is also interesting to note from these plots that the offset for T1967 is more rapid than the offset for the other trumpets, again, particularly T1780 which will also contribute to the perceived timbre of the instrument.

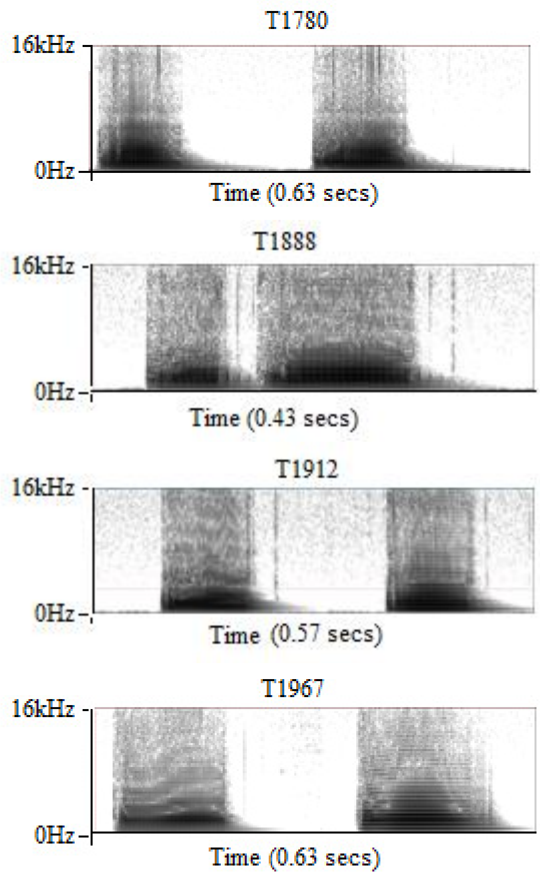

Figure 2: Spectrograms of two tongued notes to show the onset for all four trumpets.

3.3 Mouthpieces

Changing the mouthpiece of the later two trumpets changes the perceived sound considerably for both instruments. Similar analysis was therefore conducted for the different mouthpieces as for the different trumpets and LTAS graphs are shown in Figure 3. In spite of the distinct audible contrasts, the LTAS for the two mouthpieces for both trumpets reveal very similar spectral envelopes with T1912 exhibiting fewer differences than the LTAS for the two mouthpieces for T1967. The mouthpieces, similarly to the trumpets seem to have a slight impact on the energy in the frequency region of 10-15kHz, the cornet mouthpiece increases the energy in this area in T1967 and the modern mouthpiece appears to lower the frequency at which the peak occurs for T1912 with the peak moving from approximately 13kHz with the Modern mouthpiece to 14kHz with the Hawkes mouthpiece when playing the same piece.

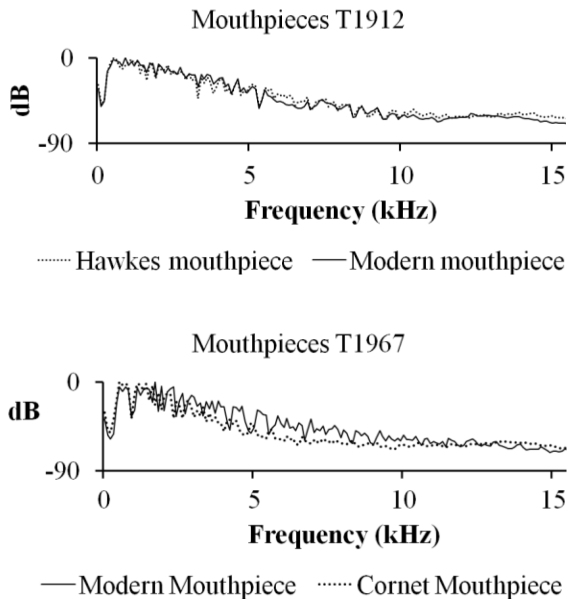

Figure 3: Showing LTAS of T1912 and T1967 with two different mouthpieces

The mouthpieces do have an impact on the spectral slope of T1967, the cornet mouthpiece exhibiting a more rapid decay in harmonics to 10kHz but increasing the effect of the higher frequency spectral peak noted above.

Figure 4 shows spectral slices of the steady state portion of the final note of piece 8 played on T1967 with the two mouthpieces. The mean fundamental frequency was obtained as 580Hz and 556Hz on the Modern and Cornet mouthpieces respectively. The spectral slice for the Modern mouthpiece presents the first and third harmonics of equal amplitude creating a double peak early in the spectrum which was also identified above in the LTAS findings. The cornet mouthpiece produces a strong fundamental with relatively strong second harmonic followed by a rapid even decay of all subsequent harmonics. Energy is no longer present at the lower frequency of 5kHz compared to 8kHz for the Hawkes mouthpiece.

Spectral slices of a steady state tone on C5, taken from piece 6, with a mean fundamental frequency of 516Hz in both cases (Figure 5) reflect the trends observed in the LTAS, that whilst the differences are more subtle than for T1967, the Modern mouthpiece on the T1912 produces a linear decay of harmonics after the fundamental whilst with the Hawkes mouthpiece there is a dip in the amplitude of the second harmonic creating the effect of a slight peak caused by the relative elevation of energy of the third harmonic.

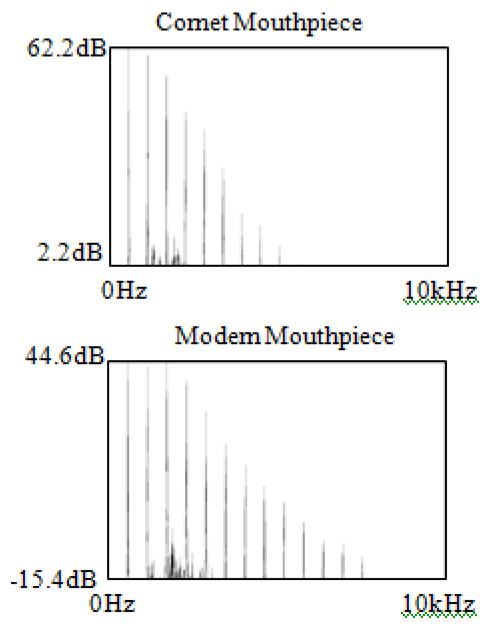

Figure 4: Spectral slices of the steady state portion of the final note of piece 8 with both mouthpieces on T1967

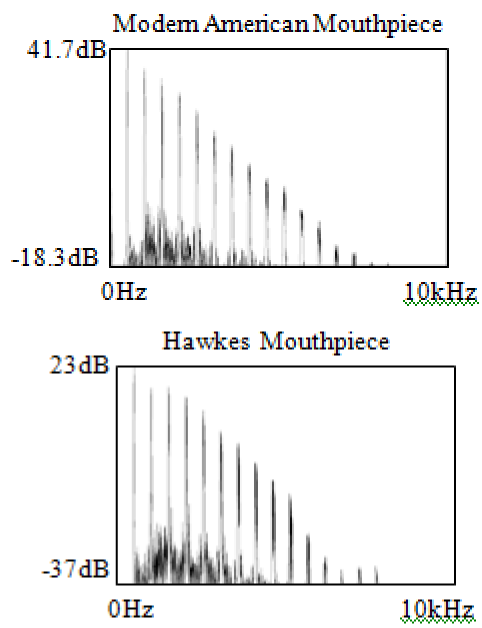

Figure 5: Spectral slices of the steady state portion of the tenth note of piece 6 with both mouthpieces on T1912

As the onsets were found to differ between instruments, onset was also considered as a factor that might change with the mouthpiece. Figure 6 shows spectrograms of T1967 playing piece 8 on both mouthpieces. There are striking differences in the onset of the notes displayed.

The Modern mouthpiece produces a much 'cleaner' pre-tone onset than the Cornet mouthpiece, illustrated in the Modern mouthpiece spectrogram as a sharp straight vertical line across the spectrum which precedes the onset of the 'note' as presented as a long tone with clearly visible harmonics. The spectrogram of the Cornet mouthpiece shows a shorter time delay from the tongued pre-tone onset, which produces time-smeared spectral energy for a longer time with frequencies across the spectrum decaying at different times to the steady state of the tone.

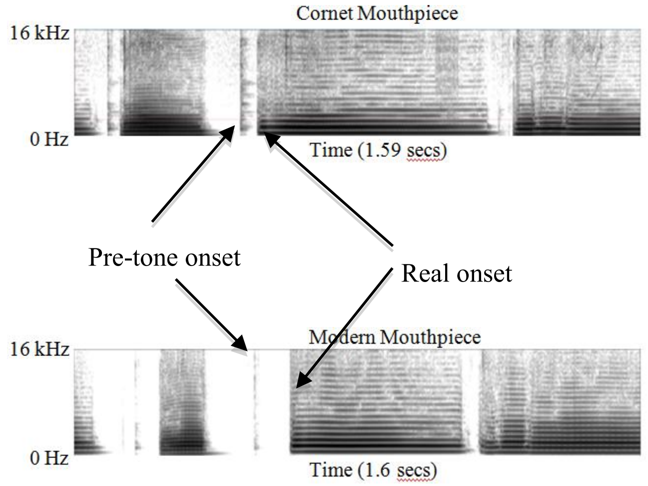

Figure 6: Spectrograms of a section of piece 8 played on both mouthpieces T1967

There is also a difference in the 'real' onset, that is when the 'pitched' note enters as a sustained sound with harmonics: the harmonics enter simultaneously in the real onset of the Cornet Mouthpiece with relative amplitude that continues throughout the tone, whereas the real onset on the Modern Mouthpiece includes a delay in the production of higher frequency harmonics. The harmonics in the steady state portion of the tones played on the Modern Mouthpiece are also better defined to 16kHz than in the Cornet Mouthpiece.

4 Conclusions

Acoustic differences are apparent between the trumpets recorded which could account for the strong opinions of players and listeners concerning the use of the baroque trumpet in modern performance. Features in the LTAS reveal that peaks in the lower frequencies of the spectrum to 2kHz alter between instruments. The rapid decay of harmonics after an initial peak in the spectrum for T1780 with a steeper slope than the other trumpets could also contribute to its unique sound. In addition, relative energy between 10kHz – 15kHz was found to alter between trumpets, but was also particularly affected by the articulation conditions for each trumpet. Considering the subtlety of the spectral differences that can be observed in the LTAS graphs for the different trumpets, the differences in onset between instruments suggest that onset characteristics are likely to be an important factor in the perceived changes in timbre. Changing the mouthpiece for the later two trumpets revealed striking differences between the onsets when the player performed the same piece whilst only slight differences were also observed in the LTAS, particularly for T1912. This supports the supposition that onset is significant to the timbral changes between trumpets and suggests that the mouthpiece is of equal if not more significance than the trumpet to the overall perceived timbre: this supports the suggestion of the performer on this occasion.

Acknowledgments

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