PERCEIVED HARMONIC RELATIONSHIP BETWEEN TONE AND TEMPO: THE EFFECT OF TIMBRE

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ABSTRACT

Background. Great Base Theory (Pound, 1938) assumes that a perceived harmonic relationship exists between the frequencies of tone and tempo. Although relatively untested this theory forms a basis for the work of a number of 20th century composers and music therapists. Recently the authors conducted an experiment employing a stimulus consisting of a tempo click superimposed upon a steady sine wave. When presented with a series of paired tone/tempo presentations employing this stimulus, participants reported a preference for the tone/tempo presentation employing the simpler integer frequency relationship. This was interpreted as indicating that listeners prefer simpler integer relationships between tempo frequency and tone frequency in a similar manner to the generally accepted preference for simple integer ratios between tones.

Aim. The aim of the current experiment is to investigate this preference for simpler integer relationships over more complex integer relationships between tone frequency and tempo frequency across a range of stimuli.

Method. Eighteen paired comparisons were presented to 64 participants. For each paired comparison participants indicated which of the two tone/tempo frequency presentations they considered to sound the most pleasant. The relative simplicity of the ratio between tempo frequency and tone frequency was measured as the Dependent variable. Tempo stimuli were a click, iterated noise segment or a pulsed tone. Tone stimuli were a sine wave, harmonic wave or inharmonic wave.

Results and Conclusion. Results suggest that the preference for simpler integer frequency relationships between tone and tempo does exist over a range of stimuli. The relationship is similar for both sine and harmonic waves but is not exhibited with inharmonic waves and is present for clicks and infratones but not for the pulsed tone.

1. INTRODUCTION

Great Base Theory (Pound, 1938) assumes that the tempo rate of a musical event is a component of that event's harmonic structure. Pound alludes to tempo as the bottom note of the harmony and the "base" or basis of all frequency relationships within the harmonic structure. The prevalent scientific view however, is that perceptually fused auditory events, such as tone, and discrete auditory events, such as a tempo stimulus, occupy separate domains of perceptual experience (Monahan, 1997). Consequently, it is assumed that tone and tempo do not share between them the same harmonic relationships that are thought to exist within their respective perceptual domains (London, 2001). However, a growing number of contemporary composers, music therapists and auditory researchers support Pound's view that a unified continuum of auditory harmonicity does exist between the frequencies of tempo and tone and employ it in their respective disciplines (Lucy, 2000; Roads, 2001; Stockhausen, 1991). In his book Microsound, Curtis Roads wrote "fundamental to microsound synthesis is the recognition of the continuum between rhythm (the infrasonic frequencies) and pitch (the audible frequencies)"(Roads, 2001, p.53). In light of this relatively widespread assumption of tenets of Great Base Theory it would seem appropriate to investigate a tone/tempo harmonic relationship from a theoretical and experimental standpoint.

A paradigm that suggests a broader range of pitch perception, extending into the domain of tempo is Warren's Iterance Theory. Warren (1999) argues that "acoustic repetition can be perceived as a global percept at rates well below the pitch limit, for waveforms other than sinusoids" (p.56). Warren calls these periodic sounds infratones and their sensory attribute, infrapitch. Warren uses the term iterance to describe the perceptual attributes of both pitch and infrapitch. Infrapitch can be demonstrated using iterated segments of Gaussian noise (Warren & Bashford, 1981), a periodic stimulus with no restrictions to waveform, amplitude or phase. This stimulus is referred to as an RFN (recycled frozen noise). Using RFNs, iterance can be heard over a range of 15 octaves (.5 Hz to 16,000 Hz) (Warren, 1999). Iterance, as described by Warren argues for a broader range of perception of auditory periodicity than is currently accepted and includes the frequency ranges of both pitch and tempo.

Even accepting Warren's iterance as evidence of a perceptual continuum between tone and tempo, the ratios between tonal frequency and tempo rate are larger than that between harmonic tones. The concept of octave equivalence is one that may go some way toward accommodating these ratios, at least at a representational level. In octave equivalence the related concepts of pitch class and pitch height suggest that pitch must be regarded as a two-dimensional attribute and that tones of the same chroma but in different octaves, are treated as harmonically equivalent (Shepard, 1964). The concepts of iterance and octave equivalence form a theoretical starting point for a unified auditory harmonicity between the frequencies of tone and tempo.

In a previous experiment we investigated a perceived harmonic relationship between tone and tempo (Brennan & Stevens, 2002). We did this by taking the generally accepted view that people prefer simpler integer relationships over more complex integer relationships between tones (Schellenberg & Trehub, 1994) and investigated whether such a preference exists between the repetition rates of tone and tempo. The previous experiment

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employed a constant sine wave (tone) and the frequency of repetition of a click comprised of a short burst of gated noise (tempo). The aim of the experiment was to establish whether a preference for the simpler integer ratio between the frequencies of tone and tempo could be identified. The findings support the existence of a preference for simpler integer ratios between tone and tempo.

The current experiment attempts to refine these findings by employing a wider range of stimuli. This approach was taken to better understand which factors contribute to the perception of a harmonic relationship between tone and tempo. In addition to the click stimulus employed in the previous experiment an infratone and a pulsed tone were included as tempo stimuli. The infratone is included to assess Warren's iterance as a temporal stimulus. If, as anticipated, it proves a viable tempo stimulus it could facilitate subsequent tone/tempo experiments employing a common stimulus type (RFNs) for both tone and tempo. The pulsed tone is included because unlike tone, the tempo of a musical event need not necessarily constitute a separate physical stimulus, it can be implied by other factors within the event. The pulsed tone was chosen as a simple example of this effect, the pulse repetition rate of the tone serving as the tempo stimulus.

Tonal stimuli in the experiment reported here comprise a harmonic wave and an inharmonic wave in addition to the sine wave employed in the previous experiment. The harmonic waveform is made up of a fundamental and its first three harmonics (f, $2f$, $3f$, $4f$). It is expected that the harmonic waves' more complete harmonic series will serve as a better predictor of a tone/tempo relationship than the sine wave. The inharmonic wave consists of an identical fundamental frequency to the harmonic and sine waves plus a three tone inharmonic series based upon a pseudo-octave. The intervals employed are drawn from Sethares' "Challenging the Octave" sonic demonstration (Sethares, 1997, p154) and constitute f, $2.1f$, $3.24f$, $4.41f$. It is anticipated that because of the inharmonic nature of this series the inharmonic wave will be a less effective predictor of a simpler integer relationship between tone and tempo than either the harmonic wave or sine wave.

In a post-experiment interview after the previous experiment it became clear that the word preference did not always suggest "most consonant" to some participants. The use of the word consonant would have been unfamiliar to many of the participants and so the description pleasant was felt to be the best compromise. In the present experiment the dependent variable is which tone/tempo ratio in a paired comparison participants report as most pleasant.

1.1. Aim, Hypotheses and Design

The aim of the present experiment was to investigate the perceived harmonic relationship between the repetition rates of tone and tempo as suggested by Pound's (1938) Great Base Theory. The experiment was designed to examine the relationship across a range of tone and tempo stimuli.

The 3 x 3 x 2 experimental design comprised the independent variables tone stimulus (harmonic wave, sine wave, inharmonic wave), tempo stimulus (click, infratone, pulsed tone) and tone/tempo frequency ratio (simpler, more complex).

The dependent variable was whether participants indicated the simpler integer tone/tempo ratio to be more pleasant than the more complex tone/tempo ratio.

It was hypothesized that overall, participants identify the simpler integer ratio between the frequencies of tempo and tone as more pleasant than the more complex integer relationship. It was further hypothesized that for tonal stimuli this relationship is most pronounced for the harmonic tone and least pronounced for the inharmonic tone and that there is no difference between the three levels of tempo stimulus.

2. METHOD

2.1. Participants

The 64 participants were from the general population. Participants reported no known hearing defects and no musical training over two years duration. Ages ranged from 20 to 48 years (mean = 28.66 years, SD = 8.88 years).

2.2. Stimuli

Stimuli were a series of 18 tone/tempo presentations. Each tone/tempo presentation consisted of one of three tone stimuli presented concurrently with one of three tempo stimuli. The nine possible tone/tempo stimulus combinations were each presented at the simpler and more complex levels of the tone/tempo frequency ratio, making a total of 18. Each tone/tempo presentation had duration of eight seconds.

Tone stimuli were a harmonic wave, a sine wave or an inharmonic wave. Tempo stimuli were a click, an infratone or a pulse rate applied to the tone. Tempo stimuli were in all cases presented at a rate of 2 Hz, the pulsed tone tempo stimulus employing a 50/50 mark/space ratio.

The fundamental frequency of the tonal stimulus was manipulated to form the simpler or more complex levels of the tone/tempo frequency ratio. All tonal stimuli were presented with a fundamental frequency of 128hz in the simpler integer condition and a frequency of 134.4 Hz in the more complex integer condition. As a ratio the simpler integer condition can be represented as 64/1, or in musical notation a perfect six octave interval. The more complex integer condition represents a ratio of 667/10, or in musical notation six octaves plus a minor second.

2.3. Equipment

Stimuli were created on an iBook G3 600mhz computer using Max/MSP software and were generated through an MOTU 828 audio interface using 24bit 44100hz resolution. Amplification was a Jands SP400 studio monitor amplifier and an Alesis Monitor Two studio reference speaker.

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2.4. Procedure

Participants listened to a series of 18 paired comparisons presented in one of eight random series. Each paired comparison comprised the simpler integer and more complex integer levels of the same type of tone/tempo presentation (e.g. sine/infratone) played one after the other. The series comprised the nine possible tone/tempo stimulus combinations presented with the simpler integer tone/tempo presentation as the first presentation of the pair and the same nine tone/tempo stimulus combinations with the simpler integer ratio as the second presentation of the pair. After each paired comparison participants were asked to indicate whether they considered the first or second tone/tempo pairing to be the most pleasant and there was a 30 second pause between each paired comparison.

Participants were tested in groups of two to six and were played the stimulus at a comfortable level through a single speaker in a room with low ambient noise. Counterbalancing of the presentation order was employed after each eight participants and the experimental session lasted approximately 15 minutes.

3. RESULTS

Results support the general hypothesis that participants report a simpler integer ratio between the frequencies of tempo and tone as more pleasant than a more complex integer relationship $t(63) = 6.38$, $p < .001$.

Stimulus	Click	Infratone	Pulsed Tone
Harmonic	0.73	0.66	0.59
Sine	0.76	0.65	0.57
Inharmonic	0.39	0.50	0.52

Table 1: Indicates proportion of participants indicating simpler integer tone/tempo ratio to be more pleasant for each tone stimulus/tempo stimulus combination.

The hypothesized greater proportion of participants reporting the simpler integer tone/tempo relationship to be more pleasant for the harmonic tone when compared to the sine tone did not occur. There being no significant difference between harmonic and sine tones for any of the three levels of tempo stimulus. The difference between the sine tone and inharmonic tone was however significant for both the click $t(63) = 6.70$, $p < .05$ and infratone $t(63) = 2.93$, $p < .05$ levels of tempo stimulus. There was also a significant difference between the harmonic and inharmonic tones for the click $t(63) = 5.91$, $p < .01$ and infratone $t(63) = 2.81$, $p < .05$ levels of tempo stimulus. As expected there was no significant difference between any of the tone stimuli at the pulse level of tempo stimulus.

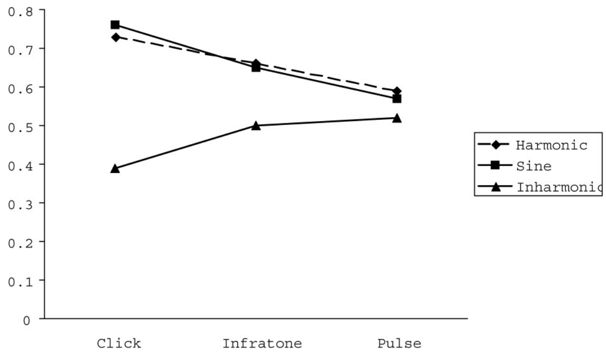

Figure 1: Displays proportion of participants reporting the simpler integer ratio as more pleasant for the three levels of tone stimulus across the three levels of tempo stimulus.

The tempo stimuli showed no significant difference between the infratone stimulus and either the click or pulse tempo stimulus at each of the three levels of tone stimulus. There was however a significant difference between the click and pulse tempo stimuli at each of the three tone stimulus levels, Harmonic $t(63) = 2.13$, $p < .05$, Sine $t(63) = 3.33$, $p < .05$ and Inharmonic $t(63) = -2.02$, $p < .05$.

4. DISCUSSION

The results lend general support for a perceived harmonic relationship between the frequencies of tone and tempo at least at the level of stimulus complexity employed. This in itself is of interest and replicates results from our earlier experiment (Brennan & Stevens, 2002). The aim of the present experiment however was to broaden the range of tone/tempo stimuli employed in an effort to better understand which factors contribute to the perception of a harmonic relationship between tone and tempo. In this context the results suggest several clear outcomes and a number which require further examination.

Results for the tempo stimuli support the hypothesis at two of the three stimulus levels. Clicks and infratones were predictors for the simpler integer ratio between the frequencies of tone and tempo being reported as the more pleasant. While the results for the click stimulus were anticipated the results for infratones are especially encouraging. As suggested earlier this should allow the construction of an experiment employing RFNs as both tonal and temporal stimuli. It is however of concern that the pulsed tone did not display the same relationship. The pulsed tone was included to test the relationship when the tempo was implied by the repetition rate of the tone stimulus rather than being created by a separate stimulus. This would have been a strong predictor for the relationship in more ecologically valid musical events and further experimentation is required to identify why this stimulus did not behave in the same manner as the discrete tempo stimuli.

When comparing the tonal stimuli, the results suggest that both harmonically unambiguous stimuli (harmonic, sine) serve as predictors of the simpler integer ratio between tone and tempo being reported as the more pleasant. It was hypothesized that the harmonic wave would have greater effect but this was not the case. As expected the inharmonic wave was not as effective as the harmonic and sine waves in eliciting a report of the simpler integer tone/tempo relationship being more pleasant. In fact it was almost exactly chance for the pulsed and infratone conditions.

An unusual result was recorded for the inharmonic/click condition. The inharmonic/click condition showed a significant proportion of participants indicating the more complex integer tone/tempo relationship to be more pleasant. It is possible that the inharmonic tone series based on Sethares' (1998) pseudo-octave was more consonant with the tempo frequency in the more complex integer tone/tempo condition than the simpler integer tone/tempo condition. Even if this were the case however, it is not clear why this effect only occurred for the click tempo stimulus. In retrospect it may have been wiser to construct an inharmonic wave with no theoretical relationship to any of the other components. The possibility that the effect described above has occurred however suggests that further experiments focussing on this particular paradigm and conducted both within and between the perceptual domains of fused and discrete auditory events would be of interest

The experiments conducted thus far have compared octave based tone/tempo frequency relationships with far more complex tone/tempo frequency ratios. This was done in order to best identify the existence or otherwise of the hypothesized perceived harmonic relationship between tone and tempo. Having established some level of support for such a relationship the next logical step would seem to be to examine this effect over a range of integer relationships with the aim of identifying intermediate levels between these extremes.

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