# THE TRITONE PARADOX AMONG CHINESE CHILDREN AGED 12 AND 13

*Diana Deutsch*[+], *Cong Jiang*[*], *Trevor Henthorn*[+], *Shibin Zhou*[*]

[+]University of California, San Diego, USA, [*]Capital Normal University, Beijing, China

## ABSTRACT

The tritone paradox is produced by a basic pattern that consists of an ordered pair of Shepard tones that are related by a half-octave (i.e., a tritone). When listeners judge whether such tone pairs ascend or descend in pitch, their judgments show systematic relationships to the positions of the tones along the pitch-class circle: Tones in one region of the circle are heard as higher and tones in the opposite region are heard as lower. However, listeners disagree as to which tones are heard as higher and which as lower; further, their perceptions vary with their languages or dialects, which in turn involve differing pitch ranges for speech. Studies on the tritone paradox have so far studied only non-tone language speakers, and teenage children have not so far been tested. This study explored perception of the tritone paradox in Chinese children aged 12 and 13 who were living in Beijing. All subjects spoke Mandarin, but the dialects that were spoken by their family members varied. Overall, a very strong tritone paradox was obtained. Pitch classes B and C tended to be judged as higher than the other pitch classes, with the plot of peak pitch classes falling off on either side of these. This finding probably reflects the most frequent pitch ranges of speech in Northern Chinese Mandarin dialects.

## 1. INTRODUCTION

The tritone paradox is a musical illusion that reflects an influence of speech on perception of musical patterns (Deutsch, 1991, 1992, 2007, 2013; Deutsch *et al.,* 1987, 1990, 2004, Ragozzine and Deutsch, 1994). The basic pattern that produces this illusion consists of an ordered pair of Shepard tones that are related by a half-octave (i.e., a tritone). So, for example, C might be presented followed by F#, or D followed by G#, and so on. Each tone consists of six sinusoids that stand in octave relation, and their amplitudes are determined by a bell-shaped spectral envelope (Figure 1). Since such tones lack the other harmonics that are needed to define a fundamental, their perceived heights are ambiguous, but their pitch classes are clearly defined.

The tritone paradox has two surprising features. First, when a given tone pair is presented (for example, D followed by G#) one listener might clearly hear an ascending pattern, while another listener might just as clearly hear a descending pattern instead. Yet when another tone pair is presented (for example, G followed by C#) the first listener now hears a descending pattern and the second listener hears an ascending one. As a second surprising feature, the way any one listener hears the tritone paradox generally varies in an orderly fashion with the positions of the tones along the pitch class circle: Tones in one region of the circle are heard as higher and those in the opposite region as lower.

To plot a listener's perception of the tritone paradox, tone pairs are presented in haphazard order, such that each of the 12 tones within the octave serves equally often as the first tone of a pair. The tones are produced under envelopes that are placed along four different positions along the spectrum, spaced at half-octave intervals. Averaging results over these different envelope positions enables control for overall effects of pitch height and also for the relative amplitudes of the components of the tones.

It has been found that the way the tritone paradox is perceived varies with the language or dialect to which the listener has been exposed. In addition, the dialects spoken by the listener's parents exert a particularly strong influence, indicating that the way the illusion is perceived is determined by a pitch class template that develops early in life (Deutsch, 1991, 2007, Deutsch *et al.*, 2004, Ragozzine and Deutsch, 1994). Deutsch (1991) compared two groups of subjects. The first group had grown up in California, and the second group in the south of England. The two groups differed statistically in their perceptions of the tritone paradox: Frequently when a subject from California heard a pattern as ascending a subject from the south of England heard the same pattern as descending; and vice versa. Further, Ragozzine and Deutsch (1994) found that, among subjects who had grown up in the area of Youngstown, Ohio, the perceptions of those whose parents had also grown up in Youngstown differed substantially and significantly from those whose parents had grown up elsewhere in the United States. In another study, Deutsch *et al.* (2004) tested subjects whose first language was Vietnamese and who had moved to California. The first, older, group had arrived in the U.S. as adults and the second, younger, group had arrived in the U.S. as infants or children. The perceptions of these two groups of subjects were very similar to each other, and both differed substantially from those of a third group, who were native speakers of Californian English and whose parents were also native speakers of Californian English. In yet another study, Deutsch (2007) found a significant correlation between the way children and their mothers heard the tritone paradox. This was true even though the mothers had grown up in different geographical regions, and so perceived the tritone paradox differently from each other.

The present study explored perception of the tritone paradox in a group of children aged 12 and 13 who were living in Beijing, China. While the majority of the subjects had spent all their lives in Beijing, a substantial minority had lived elsewhere, in a variety of provinces, and their mothers and fathers had lived in many different regions of China. We were interested in two basic issues: First we sought to determine how strongly these children perceived the tritone paradox. Second, we sought to determine whether, taking the group as a whole, the tritone paradox still showed an effect of how the pitch class circle was perceptually oriented with respect to height, taking the group as a whole.

# 2. METHOD

## 2.1. Stimulus patterns.

The stimulus patterns were taken from Deutsch's CD *Musical illusions and paradoxes* (1995). All tones consisted of six sinusoids that stood in octave relation, and the amplitudes of the sinusoids were determined by a fixed, bell-shaped spectral envelope. Figure 1 displays, as an example, a spectral plot of the tone D-G# generated under an envelope that was centered on $C_5$. In order to control for possible effects of the relative amplitudes of the sinusoids, the tones were generated under envelopes that were placed at four different positions along the spectrum, spaced at ½ octave intervals. Specifically, the envelopes were centered at 262 Hz ($C_4$), 370 Hz ($F\#_4$), 523 Hz ($C_5$) and 740 Hz ($F\#_5$). Twelve tone pairs were produced under each of the four spectral envelopes; these consisted of the pitch-class pairings C-F#, C#-G, D-G#, D#-A, E-A#, F-B, F#-C, G-C#, G#-D, A-D#, A#-E, and B-F. Four different orderings of these 12 pitch class pairings were created. These orderings were random, except that no consecutive pairings contained tones of the same pitch class. (For example, C-F# followed by F#-C was not allowed.) The tones were presented in blocks of 12. Each block consisted of tones that were generated under one of the four spectral envelopes and contained one example of each of the 12 pitch-class pairings – so there were 16 blocks altogether. All tones were 500 ms in duration, and the tone pairs were separated by 5-sec inter-trial intervals. The blocks were separated by 1-min pauses, except that there was a 5-min break between the eighth and ninth blocks. The subjects listened to the sound patterns from the CD through loudspeakers at a comfortable listening level.

## 2.2 Subjects

Potential subjects were played 48 examples of tritone pairs produced by pure tones, and were asked to determine for each pair whether it ascended or descended in pitch. Forty-seven subjects were selected on the basis of obtaining a score of at least 90% on this test, and without regard for musical training. No subject reported any hearing problems. The subjects were 20 male and 27 female students at Huaxing Middle School in the Daxing district of Beijing. All subjects spoke Mandarin. Their average age was 12.32 years (range 12-13 years). Thirty-seven subjects reported having had private instrumental or vocal music lessons. For these subjects, the number of years of musical training averaged 4.5 years (range 1 – 10) years. Thirty-two subjects had been born and lived all their lives in Beijing; however, the subjects' parents and grandparents were from diverse provinces within China, as were their grandparents (who frequently served as caregivers).

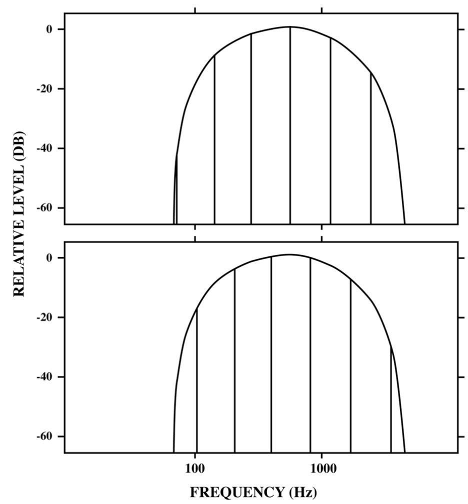


**Figure 1**. Spectral plot of a tone pair that produces the tritone paradox. Here the spectral envelope is centered at $C_5$. Upper graph represents a tone of pitch class D; lower graph represents a tone of pitch class G#.

## 2.3. Procedure

The subjects were tested during class time in a quiet room. They were first administered a questionnaire that enquired into their musical background, what languages they spoke, where they had lived, and where their parents and grandparents had lived. Following this, they were played 48 examples of tritone pairs consisting of pure tones, and were asked to determine for each pair whether it ascended or descended in pitch. It was determined that only the data from students who obtained a score of at least 90% correct on this pure tone test would be analyzed in the tritone paradox experiment, which followed. In the experiment, six tritone pairs were first presented for practice without feedback, and these were followed by the 16 experimental blocks. On each trial one of the tone pairs was presented, and the subject indicated in writing whether it formed an ascending or a descending pattern.

# 3. RESULTS

For each subject, the percentage of judgments that a tone pair formed a descending pattern was plotted as a function of the first tone of the pair. In addition, and the percentage of judgments that a tone pair formed an ascending pattern was plotted as a function of the second tone of the pair. These two sets of judgments were averaged, producing a plot of the percentage of times that each pitch class was heard as the higher of a pair. Figure 2 shows the plots produced by three of the subjects. It can be seen that all subjects showed strong relationships between pitch class and perceived height; however the form of this relationship varied clearly across subjects.

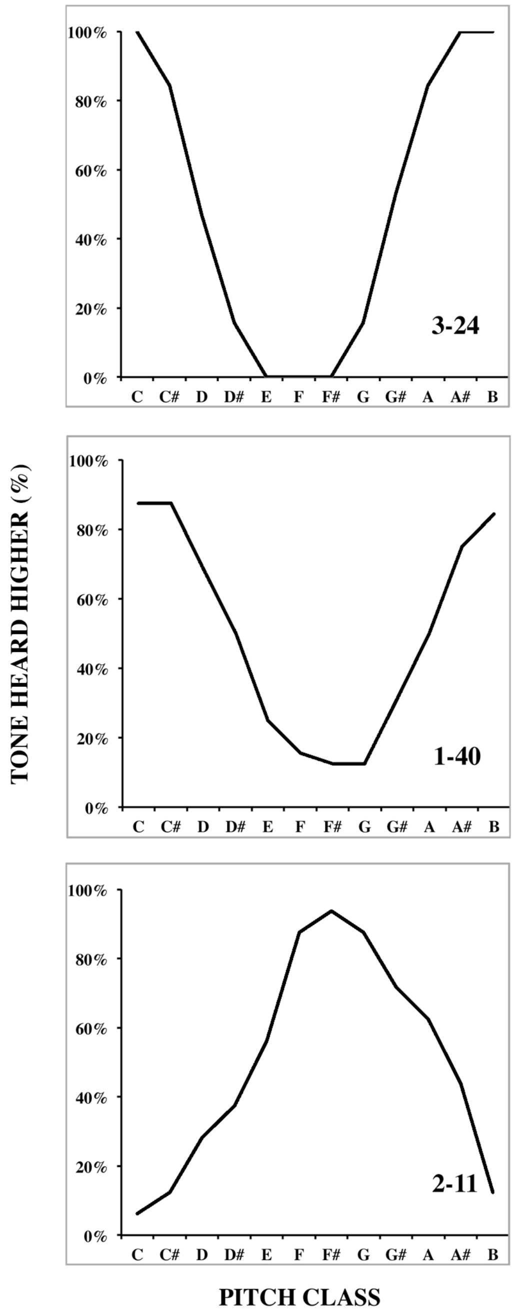


**Figure 2**. Percentages of trials in which a tone was heard as the higher of a pair, plotted as a function of the pitch class of the tone. The data from three individual subjects are displayed.

To estimate the prevalence of tritone paradox in the subject population as a whole, the following procedure was employed. First, it was determined for the scores of each subject separately whether the pitch class circle could be bisected such that none of the scores in the upper half of the circle was lower than any of the scores in the lower half. The data of 39 of the 47 subjects met this criterion. Next, a baseline estimate was obtained of the probability of obtaining such a result by chance: The scores of each subject were subject to 1 million permutations, and the probability of meeting this criterion was thereby evaluated. Averaged across subjects, the probability of a subject meeting this criterion by chance was 5.29%. The combined probability that 39 of 47 subjects would meet this criterion is therefore vanishingly small, so we conclude that the tritone paradox exists to a highly significant extent in this population.

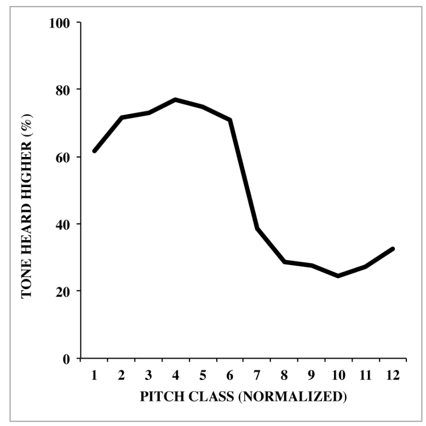


**Figure 3.** Percentages of trials that a tone was heard as the higher of a pair, plotted as a function of the pitch class of the tone. The data were averaged across all subjects and across all four spectral envelopes, and the orientation of the pitch class circle was normalized across subjects.

We next explored the form of relationship between pitch class and perceived height in this population as a whole. The orientation of the pitch class circle was normalized across subjects using the following procedure. First, for each subject the pitch class circle was bisected so as to maximize the difference between the averaged scores within the upper and lower halves. The circle was then oriented so that the line of bisection was horizontal. The data were then retabulated, with the leftmost pitch class of the higher half of the circle taking the first position, its clockwise neighbor taking the second position, and so on. The normalized data were then averaged across subjects. The resultant graph is shown in Figure 3, and it can be seen that the overall relationship between pitch class and perceived height for this group of subjects was very orderly.

Finally we determined whether, within this population, certain pitch classes were perceived as higher, and others as lower. It had been found, for example, that native English-speaking Californians tended to hear pitch classes from B to D# (moving clockwise along the pitch class circle) as higher, and those from E to A# as lower. In contrast, subjects from the South of England tended to hear pitch classes F#, G, and G# as higher and the other pitch classes as lower (Deutsch, 1991). To establish the form of relationship between pitch class and perceived height for the present group, for each subject the pitch classes that stood at the top of his or her pitch class circle (i.e., at positions 3 and 4 on the normalized plot) was determined. These were designated peak pitch classes.

Figure 4 shows the distribution of the peak pitch classes in the subject population. It can be seen that B and C occurred more often as peak pitch classes than did the others. However, the distribution is nevertheless quite widespread, and this probably reflects the strongly heterogeneous linguistic background of the present group of subjects.

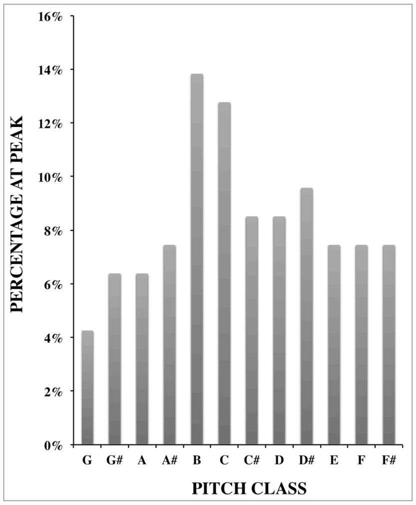


**Figure 4**. Distribution of peak pitch classes within this subject population, consisting of children aged 12 – 13 living in Beijing.

## 4. DISCUSSION

This paper provides the first study of perception of the tritone paradox in a large group of school-aged children, and also in speakers of tone language – specifically Mandarin. We found that the illusion is highly prevalent in the present population – at least as prevalent as found earlier by Deutsch *et al.* (1987) in a group of Californian English-speaking undergraduates. This high prevalence – particularly considering the young age of the subjects, may well be due to the importance of pitch height in the enunciation of Mandarin tones.

In the present experiment, it was found that pitch classes in the range from B to D (moving clockwise) were perceived as higher than the other pitch classes. In earlier work (Deutsch *et al.*, 1990, 2004) it has been hypothesized that the template that determines perception of the tritone paradox also determines the pitch range of the listener's speaking voice. And indeed, informal observations by one of us (DD) have indicated that Tone 1 (high-flat) is likely to be pronounced by people from Beijing in the range from B to D (moving clockwise). This hypothesis, linking perception of the tritone paradox to the enunciation of Mandarin tones, will be explored formally in further research.

The present findings – in addition to those of earlier studies on the tritone paradox – have implications for theories of absolute pitch. Since judgments of the tritone paradox are strongly influenced by pitch class, subjects who obtain this illusion must be using a form of absolute pitch in making their judgments. In earlier studies of this illusion, non-tone language speakers were employed, and very few if any of these subjects would have possessed absolute pitch. For speakers of non-tone language, then, the tritone paradox shows that absolute pitch must be present in implicit form – as has been argued by Deutsch and colleagues in earlier papers (see, for example, Deutsch *et al.*, 1987; Deutsch, 2013). The present subjects were not tested for absolute pitch, and it is known that this faculty is highly prevalent among Mandarin speakers with musical training (Deutsch, 2013). However, the high prevalence of the tritone paradox in the present study makes it very improbable that explicit absolute pitch (in the form of verbal labeling) was here involved to a significant extent.

## 5. REFERENCES


Deutsch, D. (1991). The tritone paradox: An influence of language on music perception. *Music Perception*, *8*, 335-347

Deutsch, D. (1992). Paradoxes of musical pitch. *Scientific American*, *267*, 88-95

Deutsch, D. (1995) *Musical Illusions and Paradoxes*, [CD with booklet] La Jolla: Philomel Records.

Deutsch, D. (2007). Mothers and their offspring perceive the tritone paradox in closely similar ways. *Archives of Acoustics*, *32*, 3-14

Deutsch, D. (2013). Absolute pitch. In D. Deutsch (Ed.) *The psychology of music, 3rd Edition*, 141-182, San Diego: Elsevier

Deutsch, D., Henthorn T. & Dolson, M. (2004). Speech patterns heard early in life influence later perception of the tritone paradox. *Music Perception*, *21*, 357-372

Deutsch, D., Kuyper, W. L. & Fisher, Y. (1987). The tritone paradox: Its presence and form of distribution in a general population. *Music Perception*, *5*, 79-92

Deutsch, D., North, T. & Ray, L. (1990). The tritone paradox: Correlate with the listener's vocal range for speech. *Music Perception*, *7,* 371-384

Ragozzine, F. & Deutsch, D. (1994). A regional difference in perception of the tritone paradox within the United States. *Music Perception*, *12*, 213-225