Dial A440 for absolute pitch: Absolute pitch memory by non-absolute pitch possessors

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Abstract: Listeners without absolute (or "perfect") pitch have difficulty identifying or producing isolated musical pitches from memory. Instead, they process the relative pattern of pitches, which remains invariant across pitch transposition. Musically untrained non-absolute pitch possessors demonstrated absolute pitch memory for the telephone dial tone, a stimulus that is always heard at the same absolute frequency. Listeners accurately classified pitch-shifted versions of the dial tone as "normal," "higher than normal" or "lower than normal." However, the role of relative pitch processing was also evident, in that listeners' pitch judgments were also sensitive to the frequency range of stimuli.

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1. Introduction

There is an apparent paradox in the way listeners process frequency information in music. Despite the transduction and encoding of sound on the basis of frequency, with tonotopic representations beginning in the cochlea, and continuing up through the auditory pathway to cortex (Merzenich and Reid, 1974; Wessinger *et al.*, 1997), in the context of music perception very few listeners are able to identify, remember, or produce musical sounds on the basis of absolute frequencies. Instead, most listeners process music in terms of relative pitch (RP); the relative differences, or intervals, between pitches.

However, this is not strictly true of all listeners. A minority of listeners, those who possess absolute pitch (AP; popularly known as "perfect pitch"), can explicitly produce or recognize an isolated tone, of say 277 Hz, as the musical pitch C#4. This ability is rare in North American culture with estimated incidences ranging from less than 0.1% in the general population (Profita and Bidder, 1988) to 15% among accomplished musicians (Baharloo *et al.*, 1998). However, cross culturally, the incidence is even higher (49%) among conservatory students who identify themselves as "Asian or Pacific Islander" (Gregersen *et al.*, 1999). This result has been confirmed using direct tests of AP ability in music conservatory students in China and the U.S. (Deutsch *et al.*, 2006).

The incidence of AP ability may be higher still if one considers more implicit forms that do not include a naming component. For example, musically trained listeners without absolute pitch can nevertheless identify whether familiar musical excerpts (Bach Preludes) were in the correct key (Terhardt and Seewann, 1983). Similarly, Schellenberg and Trehub (2003) found that listeners can discriminate original versions of familiar instrumental television theme songs from versions that were shifted in pitch by 1 or 2 semitones. Furthermore, production studies have found that even listeners without absolute pitch can sing or hum familiar songs from memory within a few semitones of the original recording (Halpern, 1989; Levitin, 1994).

In the related speech domain, Deutsch (2002) has observed that speakers of a tonal language (Vietnamese) show a high degree of pitch consistency (about 1 semitone or less) in their speech production across test sessions.

Despite the common view that absolute pitch is "special," relative pitch processing is actually quite sophisticated. For example, relative pitch processing allows listeners to correctly identify "Happy Birthday" when played on the piccolo or the cello, in the key of C or the key of G, when sung by a man or a 4-year-old girl, because the relative pitch pattern in the melody remains invariant even though the melody as a whole may be shifted up or down in frequency. In fact, most listeners may simply ignore the absolute pitch information encoded by the auditory system given that relative pitch patterns are of primary importance due to the considerable variance in absolute frequency across instruments, voices, and musical keys. In fact, theories of the psychological representation of melodic information (e.g., Deutsch and Feroe, 1981; Schmuckler, 1999) typically ignore absolute pitch information altogether.

If relative pitch processing allows listeners to perceive invariant structure amid the considerably variant absolute pitch information present in music, how do listeners process sounds for which there is little, if any, variance in frequency? There are few contexts in which this is the case. However, one, perhaps unique, example of such an "auditory standard" is the telephone dial tone, which was introduced in the 1960s. In North America, the dial tone consists of two simple tones with frequencies of 350 and 440 Hz (which incidentally happen to be related by the musical interval of a major third). Technical specifications call for tones within ±0.5% of these nominal frequencies (International Telecommunication Union, 1998). Our spectral analyses of multiple recording of dial tones produced by phones in Toronto and the surrounding area have confirmed that their frequencies are consistently within this range. For decades the dial tone has been ubiquitous, and listeners native to North America have had thousands of experiences with this particular sound. Although it hardly constitutes a sound with which musicians would choose to perform music, it does have a pitch quality for which listeners may have absolute pitch memory.

The fact that the dial tone is not musical actually makes it useful as a stimulus to test absolute pitch memory because people normally do not sing the dial tone. As a result, listeners have no motor memory associated with the production of this particular sound. This characteristic is important because previous studies have found that listeners' vocal productions for remembered music and speech in tonal languages are often quite consistent and/or accurate in their pitch content (Deutsch, 2002; Halpern, 1989; Levitin, 1994). Because it is not possible to entirely rule out memory for previous experiences of vocal tensions required to reproduce these pitches when singing along with one's favorite songs or speaking a tone language, such results may not exclusively reflect auditory memory for the music. In the likely absence of motor memory for the dial tone, however, one can be more confident that listeners' memory is auditory in nature.

The dial tone is also advantageous as a test stimulus because it is heard everywhere at the same frequency. Furthermore, because the pitch of the dial tone does not vary, it is not necessary to attach verbal labels to different pitches, as is done with musical notes (e.g., "do" or "F#"). The dial tone is simply "the dial tone," and even musically untrained listeners can say whether the dial tone sounds normal or not. This is, in fact, one of the limitations of traditional identification or production tests of absolute pitch: absolute pitch can only be tested in musically trained listeners because only they are able to use the verbal labels required for the task. Because the dial tone reflects a unique standard common to all listeners, absolute pitch memory for that standard can be tested in musically untrained listeners.

2. Experiment one

2.1 Method

Fifteen undergraduate students at the University of Toronto Scarborough participated in this experiment. They all reported normal hearing and an average 3.5 (SD=3.5) years of musical

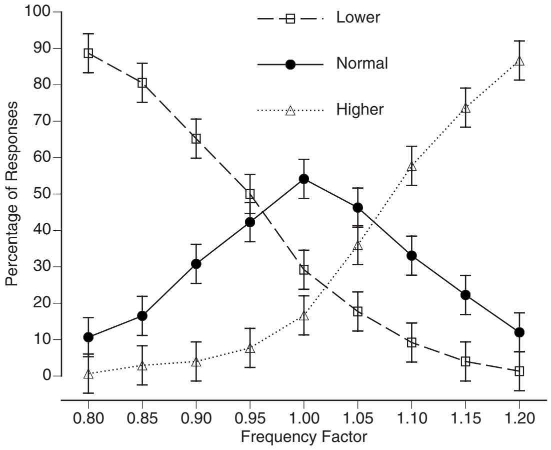

Fig. 1. The distribution of "normal," "higher than normal," and "lower than normal" responses as function of the frequency of the test dial tone from Experiment 1. The normal dial tone has a frequency factor of 1.00. Standard error bars are shown.

training, although there was no training requirement for participation. The nature of absolute pitch was defined and explained to all participants, and any listeners who believed that they possessed absolute pitch were excluded from this experiment.

Nine stimuli (i.e., test dial tones) were created by multiplying the component frequencies of the normal dial tone (350 and 440 Hz) by nine different scaling factors: 0.80, 0.85, 0.90, 0.95, 1.00, 1.05, 1.10, 1.15, and 1.20. Thus, the resulting components produced the normal dial tone when the factor was 1.00, and a higher or lower than normal dial tone when the factor was greater or lower than 1.00, respectively. The 0.5 increments represent a pitch shift of just under one semitone. Each 1-s-long auditory stimulus was generated by a PC and presented to listeners diotically through headphones, at a comfortable listening level.

On each trial listeners heard a randomly selected single test dial tone and were asked to judge whether it sounded "*normal*," "*higher than normal*," or "*lower than normal*." This experimental task was chosen because it did not require attaching a musical label to the stimulus. Because some listeners had no musical training, the experimenter ensured that each listener understood what was meant by "higher" or "lower" prior to the experiment, using a piano keyboard to demonstrate if necessary. Each listener judged each of the nine test dial tones 50 times in a random order. No feedback was given. The experimental session lasted approximately 30 min.

2.2 Results and discussion

For each listener the percentage of "*normal*," "*higher than normal*," and "*lower than normal*" responses for each of the test dial tones were calculated. Because these percentages are not independent (i.e., an increased proportion of "*normal*" responses must be accompanied by a decreased percentage of "*lower*" and/or "*higher than normal*" responses), they were treated as categorical data and analyzed using Pearson χ^2 tests. The rationale underlying this analysis is that if listeners have no absolute pitch memory for the dial tone, the distribution of these three types of responses should not significantly vary across stimuli. However, this null hypothesis was rejected as significant Pearson χ^2 scores were found for each individual listener, ranging from 168.2 to 421.5 ($M=336.20$, all p's<0.0001).

The percentage of each response for each test dial tone, averaged across the 15 listeners, is shown in Fig. 1. The percentage of "*normal*" responses significantly varied as a function of frequency, $F(8,112)=18.28$, $p<0.0001$), as did the percentage of "*higher than normal*" responses, $F(8,12)=165.15$, $p<0.0001$, and "*lower than normal*" responses, $F(8,12)$

$=160.00$, $p<0.0001$, although these latter effects are to be expected given the nonindependence of these responses. As shown in Fig. 1, listeners were increasingly more likely to respond "*normal*" when test dial tones were normal, "*higher than normal*" when they were higher, and "*lower than normal*" when they were lower.

Altogether, these results demonstrate that listeners identified the normal dial tone amid pitch-shifted variants. Although the general shape and positions of these response functions demonstrate AP memory for the dial tone, listeners' accuracy falls well below that typically found in tests with AP possessors. For example, Takeuchi and Hulse (1993) review a number of studies in which AP possessors show identification accuracy well over 70% to comparisons within a semitone. In contrast, the present results reflect a more broadly tuned sensitivity to absolute pitch information (listeners accuracy only exceeded 70% for "higher/lower than normal" responses for stimuli at least three semitones away from normal). Regardless, the fact that non-AP possessors can make accurate pitch judgments based on their absolute pitch memory is noteworthy. Experiment 2 examines the potential role of relative pitch processing in this task.

3. Experiment two

In Experiment 1, listeners differentiated the normal dial tone from pitch-shifted variants. However, because the normal dial tone was always presented in the center of the range of all stimuli, it is uncertain whether listeners' responses reflect their long-term absolute memory for the dial tone, or relative judgments based on their short-term memory for the range of stimuli tested. In other words, after a number of trials, listeners might have acquired a sense of what the highest and lowest pitches in the stimulus set were and distributed their "higher," "lower," and "normal" responses according to this range. Listeners were tested in conditions in which the normal dial tone was either above or below the center of the pitch range of the test stimuli to examine both absolute and relative pitch processing.

3.1 Method

Thirty-two undergraduate students, none of whom had participated in Experiment 1, were recruited from the undergraduate subject pool at the University of Toronto Scarborough. They had an average 2.5 ($SD=3.2$) years of musical training, although there was no training requirement for participation. As in Experiment 1, AP was defined and explained to all participants, and any listeners who believed that they possessed AP were excluded.

The stimuli were generated in the same manner as Experiment 1, but with an expanded frequency range: 0.70–1.30. The "low range" test block tested stimuli with frequency factors of 0.70, 0.75, 0.80, 0.85, 0.90, 0.95, 1.00, 1.05, and 1.10. The "high range" test block tested stimuli with factors of 0.90, 0.95, 1.00, 1.05, 1.10, 1.15, 1.20, 1.25, and 1.30.

The procedure was identical to that of Experiment 1, with the exception that the testing session was split into two blocks of trials. The order of test blocks was counterbalanced across listeners. Listeners judged whether the stimulus presented was "*normal*," "*higher than normal*," or "*lower than normal*." Within each block listeners rated each stimulus 20 times in random order. The experimental session lasted approximately 30 min.

3.2 Results and discussion

For both the high and low range stimuli the proportion of "*normal*," "*higher than normal*," and "*lower than normal*" responses were calculated for each stimulus. As in Experiment 1, for each individual listener, and for both the high and low range stimuli, the distribution of these three responses significantly varied across test dial tones, with Pearson χ^2 scores ranging from 49.5 to 263.6 ($M=137.7$, all $p's<0.0001$).

The percentage of each response at each frequency for the high and low range stimuli, averaged across listeners, is shown in Fig. 2. The proportion of "normal" responses significantly varied as a function of frequency, for the low range, $F(8,248)=27.69$, $p<0.001$, and high range stimuli, $F(8,248)=13.17$, $p<0.001$. For the high range stimuli the proportion of "*normal*" responses peaked at 49% for the normal dialtone (1.00), and for the low range range stimuli the

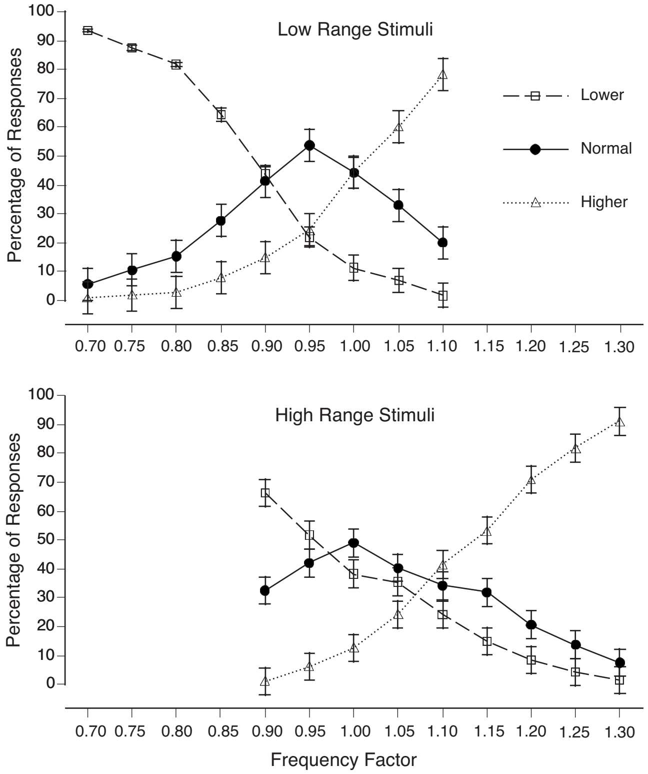

Fig. 2. The distribution of "normal," "higher than normal," and "lower than normal" responses as function of the frequency of the test dial tone for the low range (0.70–1.10) and high range (0.90–1.30) of Experiment 2. The normal dial tone has a frequency factor of 1.00. Standard error bars are shown.

peak was at 54% for the 0.95 dial tone. Thus, although the normal dial tone was shifted away from the center of the frequency range for each block, listeners were able to identify the normal dial tone to within one semitone.

The probability of responding "*higher than normal*" also significantly varied as a function of frequency, for both the high range, $F(8,248)=172.22$, $p<0.001$, and low range stimuli, $F(8,248)=146.47$, $p<0.001$. Finally, the probability of responding "*lower than normal*," varied as a function of dial tone frequency for both the high range, $F(8,248)=67.33$, $p<0.001$, and low range stimuli, $F(8,248)=248.89$, $p<0.001$. As shown in Fig. 2, listeners were increasingly more likely to respond "*higher than normal*" and "*lower than normal*" for test dial tones that were indeed higher and lower than normal, respectively.

Although listeners show fairly accurate discrimination of the normal dial tone from frequency shifted variants, listeners' responses demonstrate some sensitivity to the range properties of these stimuli. To test this statistically, difference scores were calculated by subtracting the percentage of lower responses from the percentage of higher response for each listener at each frequency level that was common across the two sets of stimuli (i.e., from 0.90 to 1.10). These difference scores (shown in Fig. 3) were submitted to a two-way repeated measures analysis of variance with the within-subjects factors of frequency (0.90–1.10) and range (low or high). As expected, a significant main effect of frequency was found, $F(4,124)=272.50$, $p<0.001$, which shows that as the test dial tones increase in frequency from 0.90 to 1.10 listeners shift from judging the test dial tones as "*lower than normal*" to judging them as "*higher than normal*."

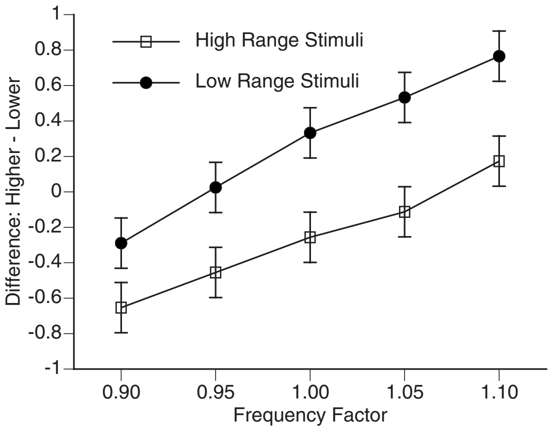

Fig. 3. Difference scores from Experiment 2, calculated by subtracting the percentage of "Lower than normal" responses from the percentage of "Higher than normal response" for the subset of stimuli common to both the high and low range stimuli. Standard error bars are shown.

A significant main effect of range was also found, $F(1,31)=112.63$, $p<0.001$, with mean difference scores of 0.27 and −0.26 for the low and high range stimuli, respectively. This difference illustrates an increased tendency to rate the same test dial tones as lower than normal when they were at the lower end of the range (i.e., the high range stimuli) than when they were at the upper end of the range (i.e., the low range stimuli), and as higher than normal when they were at the upper rather than lower end of the range tested.

The interaction between frequency and range was also significant, $F(4,124)=6.11$, $p<0.001$, and demonstrates that the general frequency range context (high versus low range) differentially influenced judgments, with the low range producing a wider range of responses across the various frequencies than the high range block. This interaction is at present difficult to interpret.

Overall, the results of Experiment 2 demonstrate both an absolute memory for the normal dial tone (as in Experiment 1), as illustrated by the broadly tuned distribution of "*normal*" responses centered to within a semitone of the true normal dial tone. Furthermore, the present results show that listeners' identification of the normal dial tone was not a simple artifact of this stimulus being presented at the center of the range of test dial tones, given that the response distributions show the appropriate skew when the normal dial tone was offset within the range of test stimuli. Finally, listeners' judgments were subtly influenced by changes in the range of the stimuli, suggesting a role for both absolute pitch memory for the dial tone in combination with relative pitch processing with respect to the range of other stimuli.

4. General discussion

The present study demonstrates that musically untrained listeners, who were not absolute pitch possessors, could nevertheless accurately identify the original telephone dial tone amid pitch-shifted variants. This finding demonstrates that over the course of everyday experience, listeners (1) have encoded the dial tone in long-term memory in a way that preserves the absolute frequency information contained in the sounds, and (2) can make accurate pitch judgments of new sounds relative to this internal standard. This ability is similar in some ways to what is typically considered absolute pitch, but also differs in some important respects.

As discussed above, the demonstration of implicit AP memory among listeners without AP is not entirely new (Deutsch, 2002; Halpern, 1989; Levitin, 1994; Schellenberg and Trehub, 2003; Terhardt and Seewan, 1983). The present study extends these results to a new context (i.e., the dial tone), one that is different is some important ways. Unlike other studies of AP, the dial tone stimulus is not musical, or even sing-able. Previous studies have employed musical stimuli that were ultimately singable, and so the potential for motor memory remains. Thus the present results can more confidently be interpreted as reflecting auditory, not motor, memory.

Although the present study lends support to the idea that some form of absolute pitch memory may be present in listeners not possessing AP in the typical sense, there remain important reasons for constraining the implications of this finding. In particular, the absolute pitch memory demonstrated here may be different from that of "true" AP possessors in important ways.

First, listeners' identification was much less accurate than that typically found in tests of true AP possessors (reviewed in Takeuchi and Hulse, 1993). Furthermore, response functions in the present study were more broadly tuned than in other studies on AP, suggesting that the absolute pitch memory in true AP possessors may indeed be different in both degree and kind. Indeed it is possible that the processing of pitch in terms of musical labels may afford AP possessors greater accuracy.

Second, although listeners appear to be sensitive to absolute pitch information, their responses were also influenced by contextual or relative pitch information. Listeners engaged in both absolute and relative pitch processing in performing this task, which is presumably different from what true AP possessors do. It is interesting to consider what factors might influence the kind of processing listeners perform in different situations. In the present study, for instance, relative pitch information was minimal. Although listeners may have been able to estimate the range of stimuli, the fact that each trial contained only one dial tone, and that the dial tones were randomly selected, may have emphasized the use of absolute pitch information. In contrast, had the dial tones been combined into short melodic patterns, relative pitch processing might have been a more natural mode of processing, causing a loss of sensitivity to the absolute pitch information altogether.

Third, there is the issue of generalizability. The dial tone tested here (consisting of 350 and 400 Hz components) is standard to North America. However, dial tones vary from country to country (International Telecommunication Union, 2003). For example, most Europeans are familiar with a dial tone consisting of a single 425 or 440 Hz component. Accordingly, an important test of many of the processes discussed here would involve examining whether foreign listeners demonstrate a similar AP memory for their local dial tone. A European replication would be particularly interesting because it would also permit an examination of potential timbral influences on AP. Because the North American dial tone is made up of a combination of tones, it has a characteristic timbre that may also aid listeners' identification. Thus, a cross-cultural test of dial tone memory would provide a valuable extension of the current findings.

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