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Standard-interval size affects interval-discrimination thresholds for pure-tone melodic pitch intervals

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Abstract

Our ability to discriminate between pitch intervals of different sizes is not only an important aspect of speech and music perception, but also a useful means of evaluating higher-level pitch perception. The current study examined how pitch-interval discrimination was affected by the size of the intervals being compared, and by musical training. Using an adaptive procedure, pitch-interval discrimination thresholds were measured for sequentially presented pure-tone intervals with standard intervals of 1 semitone (minor second), 6 semitones (the tri-tone), and 7 semitones (perfect fifth). Listeners were classified into three groups based on musical experience: non-musicians had less than 3 years of informal musical experience, amateur musicians had at least 10 years of experience but no formal music theory training, and expert musicians had at least 12 years of experience with 1 year of formal ear training, and were either currently pursuing or had earned a Bachelor's degree as either a music major or music minor. Consistent with previous studies, discrimination thresholds obtained from expert musicians were significantly lower than those from other listeners. Thresholds also significantly varied with the magnitude of the reference interval and were higher for conditions with a 6- or 7- semitone standard than a 1-semitone standard. These data show that interval-discrimination thresholds are strongly affected by the size of the standard interval.

Author Keywords

Auditory Perception; Psychophysics; Pitch-interval discrimination; Relative Pitch; Music Perception

1. Introduction

Perceiving changes in pitch is important for communication, social interaction, and making sense of an acoustic environment. In speech, pitch changes can indicate emotion, affect, and the linguistic meaning of an utterance. For example, tonal languages rely on the direction of vocal pitch change, or a *pitch contour*, to convey meaning through lexical tone (Ye and

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Connine, 1999) while pitch contours and vocal pitch levels add emotional valence, arousal, and other nonverbal meaning to speech in non-tonal languages (Bänziger and Scherer, 2005; Grichkovtsova et al., 2012; Scherer, 2003; Scherer et al., 1984). The amount by which pitch changes –defined as a *pitch interval*– is also important for conveying information in certain contexts; in non-tonal languages it may be used to emphasize certain emotions (Curtis and Bharucha, 2010) and in tonal languages it differentiates two lexical tones that share the same pitch contour, as in the low-level, mid-level, and high-level tones of Cantonese (Cutler and Chen, 1997; Ma et al., 2006)

Pitch changes are also the foundation of musical composition. Musical intervals, which are quantified in units of a *semitone*, form melodies when they are combined sequentially and harmonies when they are combined simultaneously. In Western musical theory, different intervals serve different functional roles and convey different emotions. The interval of 7 semitones, called a perfect fifth, is used to create harmonious and consonant sounds, while the 6-semitone interval, called an augmented 6th or *tri-tone*, was historically used to create musical tension and dissonance (Cooke, 1959). Pitch-interval perception and our ability to discriminate between pitch intervals of different sizes is thus an important aspect of both speech and music perception, and is commonly studied in auditory perceptual research.

Such studies of pitch-interval perception use a variety of paradigms ranging from the method of adjustment (Demany and Semal, 1990; Plomp and Steeneken, 1968; Ward, 1954) and subjective ratings (Kameoka and Kuriyagawa, 1969; McDermott et al., 2010b; Plomp and Levelt, 1965; Russo and Thompson, 2005; van de Geer et al., 1962), to interval identification and discrimination (Burns and Campbell, 1994; Burns and Ward, 1978; Killam et al., 1975; Siegel and Siegel, 1977a; Zatorre and Halpern, 1979). Interval identification paradigms, which require listeners to name intervals of the Western musical system using labels such as “minor second” and “perfect fifth”, have shown that musicians demonstrate learned categorical perception for the 12 canonical intervals of the Western musical system (e.g. 1 semitones or 2 semitones) (Burns and Campbell, 1994; Burns and Ward, 1978; Siegel and Siegel, 1977a, 1977b; Zatorre and Halpern, 1979) and have greater difficulty identifying non-canonical intervals such as quarter tones (i.e. 2.5 semitones or 0.5 semitones) without explicit training (Siegel and Siegel, 1977b). Musical training also enhances interval perception by enabling listeners to more easily detect changes made to a single note embedded in a short musical melody (Dowling and Fujitani, 1971; Dowling, 1978); listeners without musical experience can only detect brief melodies with altered intervals if the contour of these melodies is also altered. Additional studies of interval perception show that relative pitch perception is influenced by a variety of other stimulus factors, including harmonicity (McDermott et al., 2010a; Plomp et al., 1973; Trainor, 1996), timbre (Russo and Thompson, 2005; Zarate et al., 2013), sound level (Thompson et al., 2012), and whether the interval is ascending/descending or simultaneous/sequential (Killam et al., 1975; Luo et al., 2014; for a review, see Burns, 1999).

Due to the highly musical nature of interval perception, many paradigms feature stimuli in a musical context (as in the short melodies above), or require a minimal amount of musical experience by the listeners (as in the musical interval identification tasks). But because this often precludes the possibility of examining this perceptual ability in listeners without

formal musical training, many investigators instead use pitch-interval discrimination tasks to avoid reliance on musical experience. In a pitch-interval discrimination task, also called an *interval discrimination task*, listeners are presented with two intervals and are asked to judge which is larger. This task is similar to basic frequency discrimination tasks except that listeners are asked to identify the larger interval rather than the higher tone. Not surprisingly, such studies show that discrimination performance improves as the difference between the two intervals increases and that musicians typically perform the task better than non-musicians, even without an explicit musical context (Burns and Ward, 1978; Luo et al., 2014; McDermott et al., 2010a; Zarate et al., 2013, 2012).

Yet, studies of pitch-interval discrimination report conflicting results about how listeners are affected by the size of the reference interval. Listeners in several studies (Burns and Ward, 1978; McDermott et al., 2010a) produced thresholds which did not significantly differ across different standard intervals. The minimum difference (quantified in semitones units) needed to discriminate a 1-semitone interval from a slightly larger interval is the same as needed to discriminate between a 4-semitone interval and a slightly larger one. This trend holds true for standards that are both canonical (1 semitones, 2 semitones) and non-canonical (1.5 semitones, 2.5 semitones) Western musical theory intervals (McDermott et al., 2010a). However, a more recent study examining a wide range of standard interval sizes showed that discrimination thresholds strongly varied with standard interval size and were higher for larger standard intervals, increasing by an average of 0.22 semitones for each interval-standard increase of 1 semitone (Luo et al., 2014).

The different effects of standard-interval size across studies may stem from a number of factors, including the extent of the base tones' frequency rove, whether the stimuli were pure or complex tones, and, in particular, the musical experience of the listeners. The existence of an effect of standard interval magnitude for certain listeners may have important implications for our understanding of relative pitch perception. Furthermore, if the effect is influenced by musical training, an examination of this type of perception may shed light on potential differences between the listening strategies of musicians and nonmusicians.

The goal of the current study was thus twofold: to examine how listeners' pitch-interval discrimination thresholds vary with the size of the standard interval across large intervals, and to examine whether previous conflicting reports of the effects of standard interval size might be due to differences in musical training. To this end, listeners were tested in a melodic pure-tone interval-discrimination task with a procedure analogous to that used by McDermott *et al.* (2010a) and Luo *et al.* (2014) to explore pitch-interval discrimination by nonmusicians, amateur musicians, and professionally trained musicians across three standard-interval sizes: 1, 6, and 7 semitones. Standard intervals of 1, 6, and 7 semitones are sufficiently large to show a possible interval-magnitude effect, but not so large that they introduce problems with frequency roves. We included both 6- and 7-semitone conditions because, although similar in semitone size, these two intervals are radically different in their functional and theoretical role in Western musical theory. They are also larger than many standards used previously.

Since musical training is well known to affect pitch and interval perception (Kishon-Rabin et al., 2001; Micheyl et al., 2006; Spiegel and Watson, 1984), and differences in the musical experience of the listeners may explain previous discrepancies in the effect of interval size, both musicians and nonmusicians were tested. Furthermore, because the degree of musical training can highly vary from musician to musician, we separated the musicians into two subgroups: those who had formal music theory instruction which included one year of ear training and those who did not receive such formal training. Formal music theory instruction includes training in the harmonies, tonalities, and intervals of the Western musical system, and when taught in a university setting is almost always paired with a standardized ear training/sight-singing curriculum. Ear training/sight-singing classes teach students how to recognize intervals, discriminate between them, and vocally produce them without reference tones. These tasks are practiced either outside of a musical context or with the intervals embedded in a musical melody, and are intended to develop a musician's sense of relative pitch. It was therefore expected that although musicians would perform better than nonmusicians in general, ear training might lead to additional improvements in discrimination performance and produce thresholds that were consistent across different interval standards.

2. Methods

2.1. Listeners

Fourteen adult listeners participated. All reported normal hearing, none had absolute pitch, and none spoke a tonal language. Listeners were classified into three groups based on musical experience. Five nonmusicians (all males, mean (M) = 26 years of age, standard deviation (SD) = 4 years) had less than three years of musical instruction during childhood. Three of the nonmusicians had no musical experience and two had 9 months and 3 years respectively, both at least ten years prior to the experiment. The nonmusician with 3 years of musical training reported that this training was intermittent and informal, and as a result he could not play an instrument or read music. Three amateur musicians (1 male, 2 females, M = 24 years of age, SD = 3 years) had between 10 and 12 years of music lessons but no formal music theory instruction. All amateur musicians reported that they regularly played music recreationally, and were considered amateur because they had never studied music theory or received formal ear training. Six expert musicians (4 males and 2 females, average age M = 26 years, SD = 6 years) were either currently pursuing or had earned a Bachelor's degree as either a music major or music minor, had at least 12 years of music lessons, and 1 year of a college ear training/sight-singing course (M = 17 years of experience, SD = 7 years). Of the six expert musicians, two were classically trained in both piano (primary instrument of one) and violin (equal proficiency for the other musician). Two were classically trained in guitar (primary instrument of one), piano (primary instrument of one), and violin. One was a jazz violin and mandolin player (equal proficiency), and one was a jazz drummer. The two jazz artists were enrolled in a University music degree program and regularly engaged in musical study and composition, although the jazz drummer did not play a pitched instrument. The guitarist had completed ear training three years prior to the study and was actively engaged in recreational musical practice. The remaining three pianists had completed their training at least five years prior and did not practice regularly: one engaged

in musical activities every 1–2 months and two reporting playing only a few times a year. Listeners were financially compensated for their time and all procedures were approved by the University of California, Irvine Institutional Review Board.

2.2. Stimuli and Equipment

Each trial contained four sequential pure tones grouped into two melodic pitch intervals. Tones 1 and 2 defined interval A and tones 3 and 4 defined interval B. All tones were 500 ms in duration with 20 ms linear on/off ramps. The two tones of each interval were separated by a 250-ms gap and the two intervals of each trial were separated by a 1000-ms gap. All stimuli were generated in Matlab (Natick, MA) and played over Sennheiser HD380 pro headphones at a sampling rate of 44.1 kHz. To ensure that every listener heard all tones of the experiment at the same sound level, stimuli were inverse filtered with the headphone transfer function to generate an at-eardrum sound level of 70 dB SPL, measured using a 6-cc coupler, 0.5-inch microphone, and a Precision Sound Analyzer (Brüel & Kjær, Model 2260). All testing was administered in a double-walled acoustic sound booth.

The second tone of each interval was always higher in frequency than the first. The two intervals of a trial were always unequal in magnitude, and listeners were instructed to indicate which was larger using a mouse click. Visual feedback was provided. The sizes of the two intervals of each trial are designated i and $i \pm \Delta i$, where i is the magnitude of the standard interval (fixed within a run) and $i \pm \Delta i$ is the magnitude of the comparison interval.

Δi is the difference in magnitude between the two intervals and its value for each trial was determined via an adaptive staircase method (see section 2.3). The order of presentation of the two intervals was random and counterbalanced across trials.

To ensure that listeners were not able to perform the task by comparison of tones 2 and 4, tones 1 and 3 were roved over a continuous range of ± 9 semitones around a center frequency of 220 Hz and were always at least 4 semitones apart. Tones 2 and 4 were always at least 0.5 semitones apart, and tone 1 of the current trial was at least 0.5 semitones apart from tone 4 of the previous trial. Monte Carlo simulations confirmed that these roves were large enough that the task could not be adequately performed by choosing the interval with the highest tone.

2.3. Adaptive procedure

The value of Δi was controlled by a 2-down-1-up adaptive procedure that converged on 70.7% correct (Levitt, 1971). At the start of each run, Δi was set to 12 semitones. It was decreased after two consecutive correct trials, and increased after 1 incorrect trial. At each step, Δi was either divided by a factor of 10^y following two consecutive correct trials or multiplied by a factor of 10^y following an incorrect trial, where $y = 0.2$ up to and including the 4th reversal, and $y = 0.05$ thereafter.

Runs ended after the 50th trial. At the conclusion of each run, the threshold (in semitones) was calculated from the geometric mean of the values of Δi at all reversals except the first 3 (for runs with an odd number of reversals) or the first 4 (for runs with an even number of reversals). The mean number of reversals per run was 12.3. The minimum number of

reversals was 5 and the maximum number of reversals was 21 (both of which occurred once).

2.4. Experimental design and Procedure

The experiment followed a 3×3 mixed design (3 standard intervals by 3 levels of musical experience). Each listener performed 5 runs per condition, and all 5 runs were completed before moving to the next condition. The order of conditions was pseudo-randomized across listeners such that each condition was performed first at least once, and last at least once. Data were collected in two sessions conducted on consecutive days. Listeners completed either 1 or 2 conditions per day. Each session began with a 10-minute training period designed to familiarize listeners with the task and interface. The training period consisted of a sample run of 50 trials in which all adaptive parameters were identical to those for experimental runs, except that the value of i was 2 semitones and the frequencies of the tones were roved in a continuous ± 9 semitone range around 440 Hz (rather than 220 Hz). This was done to ensure that the training procedure was identical to the experimental procedure, but the stimuli were different enough to avoid biasing the results of any given condition. Following training, listeners completed all runs of the session. Listeners were given a minimum 3-minute break after finishing each condition, and longer breaks if requested, but were asked to complete all runs of a condition before pausing.

3. Results

3.1 Effect of Musical Experience

Figure 1 shows the individual thresholds for each subject in each condition. A between-subjects ANOVA revealed a significant effect of group [$F(2,11) = 6.238$, $p = 0.015$] with expert musicians producing the lowest thresholds of the three groups. Independent t-tests showed a significant difference between the thresholds for the non-musicians and the expert musicians [$t(9) = 2.90$, $p = 0.018$] and between the amateur musicians and the expert musicians [$t(6.360) = 3.74$, $p = 0.009$], but no significant difference between the thresholds for the amateur and non-musicians [$t(5.163) = 0.088$, $p = 0.933$]. Thus, the results for the expert musicians are consistent with previous studies showing differences between musicians and nonmusicians in pitch and interval-perception tasks (Kishon-Rabin et al., 2001; McDermott et al., 2010a; Micheyl et al., 2006; Spiegel and Watson, 1984; Zarate et al., 2013, 2012), but the results for the amateur musicians – who performed similarly to nonmusicians – are not consistent with previous findings.

To relate these results to those from prior studies that included smaller standard intervals, a one-way ANOVA was performed on the mean thresholds for the 1-semitone condition. This also showed a significant difference between the thresholds of the three subject groups, $F(2, 11) = 9.594$, $p = 0.004$. Independent t-tests again revealed a significant difference between non-musicians and the expert musicians [$t(9) = 3.91$, $p = 0.004$] and between the amateur musicians and the expert musicians [$t(7) = 3.40$, $p = 0.011$], but not between the amateur and non-musicians [$t(6) = 0.857$, $p = 0.424$].

3.2. Effect of standard-interval size

Figure 2 shows the average threshold for each group in each condition. The error bars for amateur musicians are offset slightly to the left of each data point. Thresholds were lowest in the 1-semitone condition for all listeners except two. A 3×3 mixed analysis of variance showed a significant main effect of standard interval magnitude [$F(2,22) = 16.425$, $p < 0.001$], and no significant interaction between standard interval size and group [$F(4,22) = 0.77$, $p = 0.556$]. A contrast analysis revealed a significant difference between the thresholds for the 1-semitone standard condition and the 6- and 7-semitone conditions [$F(1,11) = 17.618$, $p = 0.001$], but no significant difference between the 6- and 7-semitone conditions, $F(1,11) < 0.001$, $p = 0.991$. The increase in threshold with increasing standard-interval size markedly differs from the results of Burns and Ward (1978) and McDermott *et al.* (2010a) but is consistent with the results of Luo *et al.* (2014).

3.3 Thresholds expressed as a proportion of standard interval size

To compare thresholds across subject groups as a proportion of standard magnitude, thresholds were expressed as Weber fractions by dividing i by i (Table 1). A 2-way ANOVA performed on these fractions revealed a significant main effect of group [$F(2,11) = 13.43$, $p = 0.001$], expert musicians exhibiting lower fractions than amateur musicians and nonmusicians. There was also a significant effect of standard interval size [$F(1.14,12.53) = 20.575$, $p < 0.001$]. Fractions decreased as standard interval size increased. There was a marginally significant interaction [$F(2.28,12.527) = 3.773$, $p = 0.048$].

4. Discussion

Our results showed that, in an interval-discrimination task using pure tones, thresholds varied across different standard interval magnitudes; for the standard intervals tested in this study, discrimination thresholds were very high for standard interval sizes of 6- and 7-semitones. In agreement with previous studies, we found that thresholds for expert musicians were significantly lower than those for our other listeners, while the amateur musicians produced thresholds that were the same as for the nonmusicians.

The effect of standard interval size is consistent with the results of Luo *et al.* (2014). On the other hand, the results differ from those of multiple previous studies in which the threshold was constant across conditions with different standard-interval sizes (Burns and Ward, 1978; McDermott *et al.*, 2010a). However, there were notable differences across these studies: while Luo *et al.* (2014) tested a wide range of interval sizes, they did not specifically categorize listeners according to musical experience. And while Burns and Ward (1978) and McDermott *et al.* (2010a) included musicians and nonmusicians, they only used intervals smaller than 6 semitones; despite this limited range, the thresholds found by McDermott *et al.* (2010a) showed a slight linear trend across standard interval size. The current study tested nonmusicians, informally trained musicians, and formally trained musicians with intervals as large as 7 semitones, and found that the effect becomes apparent when comparing thresholds for small versus large intervals. Although we expected expert musicians to show an effect of standard interval size that differed from that of amateur and nonmusicians due to formal music theory instruction and ear/training sight-singing

experience, the lack of a significant interaction between musicianship and standard size does not support this expectation.

The fact that discrimination thresholds in our study increased as the size of the standard interval increased might reflect Weber's Law, which states that the just-noticeable difference increases as the magnitude of the stimulus increases. However, when thresholds were expressed as a proportion of standard magnitude, i.e. as d/i , they were not constant across conditions. Rather, d/i decreased as the magnitude of the standard interval increased.

Small intervals are common in both speech and music (Vos and Troost, 1989), and listeners' greater familiarity with small intervals may have contributed to the differences between the thresholds for the 1-semitone interval and the 6- and 7-semitone intervals.

Only the expert musicians produced thresholds that were significantly different from those for the nonmusicians, while the amateur musicians gave results nearly identical to those for the nonmusicians. Although the expert musicians also had more years of musical experience than the amateur musicians (an average of 16.8 years for the expert musicians and 10.7 years for the amateur musicians), the difference between the amateurs and experts was less than that between amateurs and nonmusicians. There may be something about the formal music theory and ear training of the expert musicians that affects pitch-interval discrimination thresholds in a way that music lessons or time spent playing an instrument does not. This has interesting implications for music theory instruction and auditory training: while musical training is known to enhance perception in a variety of ways, these benefits often require several years of musical experience. But if ear training is indeed effectively training relative pitch listening skills, then this may be one way that the benefits of structured auditory training – delivered over the course of 9-months to a year rather than the multiple years required of typical musical training – can generalize to non-musical environments. However, because we were unable to test pitch-interval discrimination before and after musical training occurred, and because both Western music theory's ear training and our current task specifically target the intervals of the Western musical system, further studies are needed to investigate how ear training/sight singing might benefit listeners in a variety of non-musical auditory tasks that extend beyond interval perception.

When considering the relative pitch and interval processing abilities that would be required for music perception in general and that have been documented in prior studies, the discrimination performance measured here may seem surprisingly poor. The high thresholds found here, especially for listeners without formal musical training, may have resulted from several factors. First, the stimuli were pure tones and thus lacked many of the additional qualities – such as timbre and harmonicity – of the stimuli generated by natural musical instruments. Secondly, the current procedure included a large frequency rove of the initial tones of each interval, which would have increased stimulus uncertainty and made the task more difficult. Lastly, listeners were asked to make judgments about the relationship between the two intervals of each trial (e.g. “which interval was wider?”) rather than simply detect a change in repeating stimuli (see Schellenberg and Trainor, 1996; Schellenberg and Trehub, 1994; Trainor, 1997); this is a task that would have been particularly challenging to listeners since humans may have poor interval perception in general (McDermott et al.,

2010a). For example, changes made to the intervals of short musical melodies can be difficult for some listeners to detect if those changes do not alter the melody's contour or harmonic structure (Dowling, 1978).

The high thresholds for expert listeners are at odds with prior studies but may result from variability in listeners' musical experience. Four expert musicians produced thresholds below 2-semitones for all three conditions, consistent with thresholds found elsewhere (Burns and Ward, 1978; McDermott et al., 2010a). Of the two expert musicians who produced markedly higher thresholds, one did not have regular experience with a pitched instrument and the other had undergone ear training six years prior to the study and had not practiced music in six months. It is possible that the superior performance on pitch tasks by expert musicians arises from recent and regular musical study and/or long-term experience with a pitched instrument. Additionally, the 10 minutes of training provided at the start of the study may have been inadequate for allowing some listeners to reach optimum performance. In conclusion, although the stimuli and task of the current study presented a challenge for listeners, these findings nevertheless extend the results of previous pitch-interval discrimination studies by highlighting the role of standard interval size.

5. Conclusions

Pitch-interval discrimination thresholds were found to vary with the size of the standard interval. The results suggest a potential added benefit of formal music theory and ear-training which is different from that of simple musical experience: musicians with formal musical training produced the lowest thresholds, while musicians without this training performed similarly to nonmusicians.

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Highlights

- Pitch-interval discrimination thresholds were compared at 3 standard interval sizes
- Thresholds were compared for nonmusicians, amateur musicians, and expert musicians
- Pitch-interval discrimination thresholds changed with increasing interval size
- Expert musicians produced the lowest discrimination thresholds

Figure 1.

Individual thresholds for all listeners in each group for standard interval distances of 1, 6, and 7 semitones. Thresholds for expert musicians are shown as solid black lines with filled symbols. Amateur musicians are denoted by a dashed dark grey line and filled symbols. Nonmusicians are denoted by a dotted light grey line and open symbols. Expert musicians show a high degree of variability, with some expert musicians exhibiting thresholds below 2 semitones.

Figure 2.

Mean thresholds for the three groups and for standard interval distances of 1, 6, and 7 semitones. Thresholds are lower for a 1-semitone standard interval than for 6- or 7-semitone standard interval magnitudes. Expert musicians (green) produced the lowest thresholds in all conditions. Error bars represent 1 standard error of the mean. To facilitate visual inspection, error bars for nonmusicians (blue) and amateur musicians (red) are offset slightly to the right and left of the data points, respectively.

Table 1Thresholds expressed as a Weber Fractions ($\Delta f/f$)

	1-semitone	6-semitones	7-semitones
Nonmusicians	2.05	0.74	0.68
Amateur musicians	1.66	0.77	0.69
Expert musicians	0.58	0.39	0.27