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Cues for Key Perception of a Melody: Pitch Set Alone?

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Abstract

Studies have shown that pitch set, which refers to a set of pitches of constituent tones of a melody, is a primary cue for perceiving the key of a melody. The present study investigates whether characteristics other than pitch set function as additional cues for key perception. In Experiment 1, we asked 13 musicians with absolute pitch to select keys for 60 stimulus tone sequences consisting of the same pitch set differing in pitch sequence. In Experiment 2, we asked 31 nonmusicians to select tonal centers for the 60 stimulus tone sequences. Responses made by the musicians and the nonmusicians yielded essentially equivalent results, suggesting that key perception is never unique to musicians. The listeners' responses were limited to a few keys/tones, and some tone sequences elicited agreement among the majority of the listeners for each of the keys/tones. These findings confirm that key perception is not only defined by pitch set, but is also influenced by characteristics other than pitch set such as pitch sequence.

Cues for Key Perception of a Melody: Pitch Set Alone?

When the pitches of constituent notes in a sequence of tones are organized perceptually as a "melody", listeners perceive a "key" of the sequence whether they can consciously name it or not (e.g., Abe, 1987a, 2002). The general consensus is that listeners use some kind of structural properties of melodies as cues in perceiving keys. However, it is unclear what kinds of structural properties of melodies serve as cues for key perception.

Studies have shown that key perception is defined by a set of pitches of constituent tones of a melody, referred to as "pitch set" (Abe, 1987b; Abe & Hoshino, 1990; Cross, Howell, & West, 1983; Cuddy, 1991; Cuddy & Badertscher, 1987; Hoshino & Abe, 1984; Krumhansl, 1990; Krumhansl & Kessler, 1982; Krumhansl & Shepard, 1979; Longuet-Higgins & Steedman, 1987; Oram & Cuddy, 1995; Temperley, 1999; Yoshino & Abe, 2004). Krumhansl and her colleagues have conducted a number of experiments that demonstrated the effect of pitch set on key perception. For example, Krumhansl and Kessler (1982, Experiment 1) prepared various musical elements, such as the ascending scale, descending scale, the tonic triad chord, and chord cadences, and then created two stimulus tone sequences that in differed in pitch range for each element. Listeners were presented a stimulus tone sequence, followed by one of the 12 chromatic tones, which they rated as how well it fitted with the preceding tone sequence in a musical sense. For each element, the tone that received highest rating systematically varied according to the pitch sets of the given tone sequences. The tones receiving the highest rating corresponded to the tonics of the keys in which all of the constituent tones in the given pitch sets could be interpreted as scale tones. These results suggest that the key perception of listeners systematically varies in accordance with pitch set.

Abe and his colleagues also have reported that key perception is defined by pitch set (Abe, 1987a, 1987b; Abe & Hoshino, 1990; Abe & Okada, 2004; Hoshino & Abe, 1984; Yoshino & Abe, 2004). For example, Hoshino and Abe (1984) presented tone sequences with various pitch sets to listeners, who were asked to select a final tone that could close each given tone sequence coherently as a whole. The results confirmed that the selected final tones systematically differed in accordance with different pitch sets, and that the selected final tones were basically equivalent to the tonics of keys of which all constituent tones in the pitch sets could be interpreted as scale tones. Thus, their findings indicate that key perception is dependent on pitch set.

The question arises whether key perception is defined by pitch set only. Consider the following two kinds of tone sequences:

Sequence 1: C_4-G_4-E_4-A_4-D_4-B_4

Sequence 2: D_4-B_4-C_4-E_4-A_4-G_4.

Both are composed of the same pitch set, but they differ in pitch sequence. We (the authors) perceive Sequence 1 as C major and Sequence 2 as G major. If our experience is representative, it is possible to speculate that key perception is defined by some other characteristics as well as pitch set. Previous studies have suggested this possibility (e.g., Deutsch, 1984, 1999; West & Fryer, 1990), and some of them have specifically indicated characteristics other than pitch set as additional cues in perceiving keys.

For example, Butler and Brown suggested that specific intervals in a tone sequence could serve as an additional perceptual cue (Brown, 1988; Brown & Butler, 1981; Brown, Butler, & Jones, 1994; Butler, 1989, 1990a, 1990b; Butler & Brown, 1984, 1994). Building upon Browne's theory (Browne, 1981), they proposed "intervallic rivalry theory" (Brown, et al., 1994; Butler & Brown, 1994). They postulated that "rare intervals" that occur infrequently in the diatonic sets serve as a determinant factor when they appear in a temporal sequence, implying goal-oriented harmonic motion of a type common in tonal music (Brown, et al, 1994; Butler, personal communication, October, 18, 2003). Other researchers also proposed that specific intervals function as additional perceptual cues (e.g., Huovinen, 2002; Vos, 1999). Moreover, characteristics other than specific intervals have been indicated as additional cues for key perception, for example: two and three tone transitions (Krumhansl, 1979, 1990, 2000); a grouping of consecutive pitches on the basis of pitch proximity (Deutsch, 1984); a combination of specific intervals (e.g., Vos, 2000); the last tone of a sequence (Lamont, 1998; Parncutt & Bregman, 2000); both the pitches of the opening tone and the last tone of a sequence (Cuddy, Cohen, & Mewhort, 1981; Dowling, 1991); a combination of specific pitches (e.g., Bharucha, 1984; Cuddy, et al., 1981; Povel & Jansen, 2001, 2002); and pitch salience and sensory memory decay (Huron & Parncutt, 1993).

Thus, each of the previous researchers has proposed each characteristic other than pitch set as additional cues for key perception. However, there is still little agreement about the identity and functioning of these other characteristics as additional cues in conjunction with pitch set. Identification of the kinds of characteristics that serve as cues is needed. However, before this can be done, some additional confirmation is necessary. Key perception may be possibly influenced by pitch set alone, and perception of different keys for tone sequences consisting of the same pitch set differing in its sequence may be possibly derived from chance factors other than pitch set. The aim of the present study was to confirm that characteristics other than pitch set function as additional cues in key perception. To investigate this, we used tone sequences that were derived from the same pitch set but differed in its sequence, and asked musically trained listeners and untrained listeners to identify keys/tonal centers.

The tone sequences employed in this study were generated in the following way. Pitch set was prepared on the basis of three criteria. First, listeners must be able to feel the tonality for a given tone sequence. For our participants, who have shared Western tonal schema, "tonality feeling" depends on whether the tone sequences conform to Western diatonic structure (e.g., Abe & Hoshino, 1990; Krumhansl, 1990). We used a diatonic pitch set in which all tones were interpretable as scale tones belonging to Western diatonic scale. Second, listeners must be able to perceive a key through a given tone sequence. The experimental results in Hoshino and Abe (1984) suggest that six-tone sequences are adequate for listeners to establish a key in a stable way without confusing listeners with possible modulations. Accordingly, we used six-tone sequences. Finally, we wanted to create a context in which a key would be unable to be identified by pitch set alone. Thus, we used all constituent tones that could be interpreted as scale tones belonging to multiple keys. In this way, we decided to use six different tones, and to choose a particular pitch set [C, D, E, G, A, B]. All tones could be interpreted as scale tones of the following keys: C major, G major, E minor, and A minor.

A few kinds of intervals might serve as possible cues for key perception. We wanted to examine as many possible intervals[1] as we could in relation to participants' key responses to make our study more generalizable. By applying a criterion that restricted the distance between tones within one octave, we could generate 20 possible kinds of intervals by pairing two pitches in the pitch set: (±1), (±2), (±3), (±4), (±5), (±7), (±8), (±9), (±10), and (±11)[2]. In the current study, both [C_4, D_4, E_4, G_4, A_4, B_4] (hereafter referred to as "Pitch Set I") and [D_4, E_4, G_4, A_4, B_4, C_5] (hereafter referred to as "Pitch Set II")[3] were prepared in order to generate these 20 intervals. Here, we have to note that the tone sequences in the present study did not include the intervals (±6), which are representatives of “rare intervals” (Butler & Brown, 1994). Thus, the present study was unable to examine whether the intervals (±6) function as perceptual cues for key identification. If, however, the participants are able to feel keys for the tone sequences, the result will imply that the intervals (±6) are not always necessary cues for key identification.

All possible permutations of the six different tones yield 720 sequences, out of which we chose 60 sequences. In this process, we arranged it so that each of the 20 successive intervals could occur with almost equal frequency. Of these 60 tone sequences, 24 originated from Pitch Set I and 36 from Pitch Set II.

Two experiments were conducted. Musically trained listeners with professional music education (hereafter referred to as “musicians”) participated in Experiment 1, and musically untrained listeners (hereafter referred to as “nonmusicians”) participated in Experiment 2. We wanted to assess listeners’ perceived keys by as a direct and a sensitive response measure as possible.

The musicians in Experiment 1 possessed explicit knowledge of key and self-reported absolute pitch (AP), which allowed them to consciously name the keys that they perceived. Therefore, we could ask them to name the keys for given tone sequences.

In contrast, nonmusicians could not name keys, so we adopted the experimental method of final-tone extrapolation in order to infer the keys they perceived. The final tone extrapolation method was developed by Abe and Hoshino (Abe & Hoshino, 1990; Hoshino & Abe, 1984). Using this method, listeners are asked to select a “final tone” which is to be the best fit for coherently closing the given tone sequence, but not a tone which is expected to follow the last tone in the given tone sequence. Listeners are given a keyboard and allowed to play tones on the keyboard to select a final tone. The basic assumption underlying this method is that the tone selected as a final tone is likely to be the tonic or the nuclear tone of the perceived key. Needless to say, the final tone responses are a less direct measure than the key naming responses, and might not only reflect the keys that participants perceived, but also be influenced by other factors, for example, the risk that participants misunderstood the final tones as the ending tones for the given tone sequences (Brown, et al., 1994), or a bias that was produced by playing several tones on a keyboard (Auhagen & Vos, 2000). Therefore, we tried to minimize the effect of these other factors. For example, we gave the participants the following instruction: "You must select a tone which is to be the best fit for coherently closing the given tone sequence. You do not have to select a tone which is expected to follow the last tone in the given tone sequence". Also, we permitted our participants to listen to the tone sequences and to play tones on a keyboard as many times as they wanted.

Regarding key perception of nonmusicians, Smith (1997) argued that musically untrained listeners might hear just "contourish tinkling". Hoshino and Abe (1981, 1984), however, showed that listeners, regardless of music training, perceptually organize the constituent pitches in a sequence of tones into a coherent system of tonality that is woven around a "tonal center" when they perceive the sequence as a "melody", not a jumbled sequence of tones. In the present study, we examined whether key perception would vary related to music training. If nonmusicians perceive keys for given tone sequences, they would be similar to musicians in their responses. However, if nonmusicians only perceive "contourish tinkling", then their responses would differ from those of musicians.

Although the same stimulus materials were used for the musicians and the nonmusicians, the tasks for assessing key perception were different. Therefore, the two experiments are independent, and direct statistical comparison of the two groups was not possible.

We predicted that participants' responses would be limited to the four keys (C major, G major, E minor, and A minor) for which all constituent tones of the given tone sequences can be interpreted as members of a diatonic scale. Furthermore, we made the following predictions. If participants' responses were distributed randomly among those keys, we should reject the hypothesis that characteristics other than pitch set function as additional perceptual cues for key identification. If, on the other hand, participants' responses were systematically distributed among those keys, this would support the hypothesis.

Experiment 1

Musicians participated in Experiment 1. We examined whether musicians' key identification was systematically influenced not only by pitch set but also by characteristics other than pitch set.

Method

Participants. Participants were 13 undergraduate students of Kobe College and Hokkaido University who played Western musical instruments every day, and reported they possessed absolute pitch. Their mean age was 22.4 years old, and they had 16.9 years (SD = 3.3) of music training on average. Six played the violin, four the piano, two the trombone, and one both the electronic organ and the viola.

Materials and apparatus. The stimulus materials were 60 tone sequences, which were composed of the same pitch set [C, D, E, G, A, B] differed in its sequence (Appendix 1). Of the 60 tone sequences, 24 were derived from Pitch Set I [C_4, D_4, E_4, G_4, A_4, B_4] and 36 from Pitch Set II [D_4, E_4, G_4, A_4, B_4, C_5]. All tone sequences were presented at the same tempo. To minimize the effect of metrical perception on key perception (e.g., Abe & Okada, 2004), the duration of each pitch was equal (i.e., 0.6s), for a total of 3.6s per tone sequence. All pitches were of equal intensity. The timbre of each pitch was an acoustic grand piano. These tone sequences were created as MIDI files using sequencing software (Roland "Cakewalk" software) installed on a Windows PC. The same computer controlled the presentation of the tone sequences. All tone sequences were presented at a comfortable volume through speakers in a soundproof chamber.

Procedure. Participants were tested individually or in a small group. Participants, seated in front of the speakers, were given a response sheet listing twelve major key categories and twelve minor key categories. In each trial, a tone sequence was presented three times. There were 1.2s intervals between the presentations. After the initial three presentations, participants were allowed to listen to the given tone sequence as many additional times as they requested. Participants were asked to identify the most plausible key for the given tone sequence on the response sheet, and then were asked to rate their subjective confidence in their identification on a 7-point scale (7 = *full confidence* to 1 = *poor confidence*). After three practice trials, 60 experimental trials were presented in randomized orders. The experiment lasted approximately 40 minutes including the instruction and the practice trials. At the end of the experiment, participants filled out a questionnaire about their musical background.

Results and discussion

Participants' responses obtained in Experiment 1 were the keys which they had identified (hereafter referred to as "key responses") and the confidence ratings. For each tone sequence, each of these responses was collected as follows. Key responses were classified into 24 major and minor key categories, and then the number of participants in each category was counted. We calculated the value of the coefficient of concentration of selection (*CCS*)[4] for each tone sequence. Appendix 1 shows the tone sequences of each pitch set arranged in descending order of the *CCS* values. For confidence rating, we calculated the mean ratings.

We examined which keys the participants identified for the 60 tone sequences derived from the same pitch sets but differing in sequence. Figure 1 illustrates the distribution of key responses expressed in percentages. As can be seen in Figure 1, key responses for both pitch sets were predominantly limited to three out of the 24 possible key categories: C major, G major, and A minor. C major responses constituted the largest proportion of all key responses (43% in Pitch Set I, 26% in Pitch Set II). G major responses and A minor responses constituted the second and the third largest proportion respectively (in Pitch Set I and Pitch Set II, respectively, G major: 27% and 25%; A minor: 10 % and 22 %). All tones in the present pitch set could be interpreted as scale tones belonging to each of the three keys. The results confirmed that key identification is defined by pitch set. The results are consistent with a proposal that a subset of possible keys might be implied by a tone context (Cuddy & Lunney, 1995). This subset contains keys clustered within a tonal region on the toriodal surface of keys (Krumhansl & Kessler, 1982).

Figure 1

The results that key responses were limited to C major, G major, and A minor were expected because previous studies have indicated that key perception is defined by pitch set. We further examined how the participants chose one key from among the three. As mentioned in the Introduction, if pitch set alone served as the perceptual cue for key identification, the participants' choice of these keys should be randomly distributed. In this case, there should be no tone sequence that elicited agreement among the majority of the participants in key responses. By contrast, if characteristics other than pitch set served as additional perceptual cues, then most participants' choice of these keys would have something in common. In this case, for the key responses, there should be some tone sequences which elicited agreement among the majority of the participants' C major response and, at the same time, there should be other tone sequences which elicited agreement among the majority of the participants' G major response (or A minor response).

To determine whether the participants coincidentally chose one key from among the three by using pitch set alone, we identified 21 tone sequences (out of the 60) for which seven or more of the 13 participants agreed on key responses. There was a consensus in responses for the following tone sequences: 12 tone sequences of C major (I-01, I-02, I-03, I-04, I-05, I-07, I-08, I-11, II-02, II-03, II-05, and II-06); six tone sequences of G major (I-09, I-10, II-07, II-09, II-10, and II-11); three tone sequences of A minor (II-01, II-04, and II-08). The result shows that there was a common choice of key for most participants for the tone sequences consisting of the same pitch set differing in sequence. This indicates that the participants did not coincidentally choose C major, G major, or A minor but instead the participants identified keys by using other characteristics as well as pitch set.

Confidence ratings for key responses were also obtained in this experiment, as mentioned above. The average of confidence rating across the 24 tone sequences of Pitch Set I was 4.36 (range = 3.85 – 5.38), and across the 36 tone sequences of Pitch Set II was 4.41 (range = 3.69 – 5.23). These results suggest that the participants identified keys with moderate confidence. The Kendall rank-order correlations between rankings of mean confidence ratings and *CCS* values was marginally significant for Pitch Set I, $\tau = .28$, $N = 24$, $p = .06$, and was significant for Pitch Set II, $\tau = .37$, $N = 36$, $p < .05$. The positive correlations for both pitch sets reflect the fact that the tone sequences with larger values of *CCS* received higher confidence ratings than the ones with smaller values of *CCS.* The result suggests that the degree of "tonality feeling" is dependent on pitch sequence.

In summary, as expected, key perception is defined by pitch set. It is also systematically influenced by characteristics other than pitch set.

Experiment 2

Experiment 2 used the same stimulus tone sequences as Experiment 1 to examine whether nonmusicians' key identification was systematically influenced not only by pitch set but also by characteristics other than pitch set. However, nonmusicians cannot directly name the keys that they perceive. Therefore, we used the method of final tone extrapolation to infer the perceived keys from their final tone responses

Method

Participants. Thirty-one nonmusicians participated (mean age = 22.1 years old). They were undergraduate and graduate students of Hokkaido University.

Materials and apparatus. The materials and apparatus were the same as those used in Experiment 1.

Procedure. All participants were tested individually, seated in front of the speakers in a soundproof room. They received the following written instructions: "You will hear 60 series of six tones. Each series (tone sequence) will first be presented three times. For each tone sequence, you must select a tone out of the twelve tone categories listed on the Response Sheet by using the keyboard in front of you. You should select the tone that is the most plausible tone which would be the best fit for coherently closing the given tone sequence. You do NOT have to select a tone which is expected to follow the last tone in the given tone sequence. You may listen to the given tone sequence as many times as you want and play as many tones on the keyboard as you want. After finishing the selection of the tone, you will rate your confidence in your selection of the tone on a 7-point scale (7 = *full confidence* to 1 = *poor confidence*).” Participants were given a response sheet of the twelve tone categories within one octave (C, C#, D, D#, E, F, F#, G, G#, A, A#, B) to mark their responses and confidence ratings. After three practice trials, 60 experimental trials were randomly presented for each participant. The experiment lasted approximately 60 minutes including the instruction and the practice trials. At the end of the experiment, participants filled out a questionnaire about their musical background.

In each trial, a tone sequence was presented three times, with 1.2s intervals between the presentations. After the initial three presentations, participants were allowed to listen to the given tone sequence as many additional times as they requested verbally. During and after the presentation of each tone sequence, participants were allowed to play tones on a MIDI sound keyboard (YAMAHA CBX-K1XG) to help them make their responses.

Results and discussion

Participants’ responses obtained in Experiment 2 were the tones which they had selected as final tones (hereafter referred to as “final tone response”) and the confidence ratings. For each tone sequence, each of these responses was collected as follows. Final tone responses were classified into 12 pitch categories (within one octave), and then the number of participants included in each category was counted. We also calculated the *CCS* values for each tone sequence. We calculated the mean confidence ratings.

We examined the tones the participants selected as the final tones for the 60 tone sequences derived from the same pitch sets differing in sequence. Figure 2 presents the distribution of final tone responses expressed in percentages. As can be seen in Figure 2, several tones were selected as final tones, of which tone G and tone C were frequently selected. Tone G responses constituted the largest proportion of all final tone responses (25% in Pitch Set I, 29% in Pitch Set II). Tone C responses constituted the second largest proportion (24% in Pitch Set I, 17% in Pitch Set II). Since the selected final tones were interpretable as tonics of perceived keys (Hoshino & Abe, 1984), we considered tone G as a tonic of either G major or G minor. Similarly, we considered tone C as a tonic of either C major or C minor. Some studies (e.g., Abe & Hoshino, 1990; Krumhansl, 1990) have indicated that listeners basically tend to perceive keys for which all constituent tones of a given tone sequence can be interpreted as members of a diatonic scale. If tone G (or tone C) is a tonic of a major mode, all tones of the present pitch set can be interpreted as members of the diatonic scale for G major (or C major). If, on the other hand, tone G (or tone C) is a tonic of any minor modes (natural minor scale, harmonic minor scale, and melodic minor scale), several tones of the present pitch set can be interpreted as nonmembers of the diatonic scale for G minor (or C minor). Therefore, it is likely that the participants perceived the final tone G (or C) as a tonic in a major mode rather than in a minor mode, although it cannot be directly confirmed.

Figure 2

To determine further whether the participants coincidentally chose either of these two tones on the basis of pitch set alone, we identified tone sequences (of the 60) for which more than half of the 31 participants agreed. There were five such tone sequences for tone G: I-12, II-09, II-10, II-16, and II-32. This number of such consensual tone sequences was rather small. When we shifted the criteria for the participants' agreement from half to one-third of the participants, we identified 22 such consensual tone sequences. There was a consensus in responses for the following tone sequences: 16 tone sequences, in addition to the five above, of tone G (I-04, I-06, I-10, I-16, I-17, I-21, I-23, II-11, II-12, II-17, II-23, II-25, II-26, II-29, II-31, and II-34) and six tone sequences of tone C (I-01, I-02, I-14, I-19, I-24, and II-03). Although the level on consensus was lower for these nonmusicians than the musicians in Experiment 1, still it can be concluded from these results that the participants did not coincidentally choose tone G or tone C but instead the participants systematically chose the tones according to characteristics other than pitch set.

The average confidence rating across the 24 tone sequences in Pitch Set I and the 36 tone sequences in Pitch Set II were 4.24 (range = 3.87 – 4.45) and 4.24 (range = 3.68 – 4.71) respectively. Rankings of the mean confidence ratings and of the *CCS* values were significantly correlated with each other for both pitch sets: $\tau = .32$, $N = 24$, $p < .05$ for Pitch Set I, and $\tau = .35$, $N = 36$, $p < .05$ for Pitch Set II.

In summary, the results of Experiment 2 are similar to those of Experiment 1. Nonmusicians' key identification is defined by pitch set and also is systematically influenced by other characteristics.

General Discussion

We were interested in the similarities or differences between the responses of musicians in Experiment 1 and those of nonmusicians in Experiment 2, although the two experiments differed in methodology and response options. The musicians in Experiment 1 named keys directly so that their responses could be classified into the 24 major and minor key categories. On the other hand, the nonmusicians in Experiment 2 selected final tones so that their responses could be classified into 12 tone categories. Thus, the number of possible response categories was different between the two listener groups. Therefore, in order to make the two groups of response categories comparable, we reclassified the musicians' responses into 12 tone categories according to the tonics of their key responses. Figure 3 shows the distributions of responses of the musicians and the nonmusicians expressed in percentages. Visual inspection of Figure 3 shows that both distributions of responses have several similarities. The musicians' responses were concentrated on the three tones C, G, and A. For the nonmusicians, although this tendency does not seem as obvious as that of the musicians, C responses and G responses constituted the largest proportion of all responses, and A responses constituted another large proportion. Only the nonmusicians selected not only these three scale tones but also other scale tones, for example tones D, E, and B.

Figure 3

The distributions of responses of the musicians and the nonmusicians were similar to each other. This leads us to two important inferences. First, the keys that the nonmusicians perceive are fundamentally equivalent to those that the musicians perceive. Nonmusicians, who do not know the concept of "key" and cannot consciously identify the keys that they perceive, seem to have similar perceptions of keys as trained and highly skilled musicians. Nonmusicians perceive key; they do not appear just to perceive "contourish tinkling" (Smith, 1997). Second, indirect responses obtained by the final tone extrapolation method are similar to direct responses obtained by the key naming method. This confirms that nonmusicians' responses are interpretable as tonal center of their perceived keys. In other words, the final tone extrapolation method is a valid one as a response measure for the study of key perception.

While the graphs of the musicians' and the nonmusicians' key responses are basically similar in form, there are also differences. The differences between the graphs may be interpreted as differences related music training, as previous studies indicated that there are subtle differences between musically trained and untrained listeners in key perception (e.g., Cohen, 2000). However, in any psychological experiment, generally there are some differences between the responses of experts and novices. The distribution of responses of experts usually shows a more clear-cut form than that of novices because novices' responses are generally influenced more by extraneous or chance factors than experts' response are. Furthermore, in the case of the present study, the nonmusicians' final tones responses are a less direct measure than the named-key responses of musicians.

As mentioned in Experiment 1, approximately one-third of the tone sequences (21 tone sequences) elicited agreement among a majority of the musicians in key responses. In contrast, five tone sequences elicited agreement among a majority of the nonmusicians in final tone responses, of which only two tone sequences were included among the 21 consensual tone sequences of the musicians. Thus, the proportions of consensus on the part of the nonmusicians were much smaller than found among the musicians. It is possible to make at least two different interpretations on the differences between two listener groups. One is that the tonal processing of nonmusicians is less stable than that of musicians. Another interpretation is that the use of characteristics other than pitch set differs between musicians and nonmusicians, but this interpretation seems to be questionable because our nonmusicians showed lower levels of consensus and less discriminating perception. In any case, even if it is probable that nonmusicians' tonal processing is essentially the same as musicians', differences among individuals and the instabilities of responses within an individual are likely to be larger among nonmusicians than among musicians.

In summary, the results of the present study show that listeners' key identifications were limited to a few specific keys/tones for all the tone sequences. The results also show that a third of all the tone sequences elicited agreement among the majority of listeners for each of the keys/tones. Those results suggest that, regardless of music training, listeners perceived keys of melodies by use of other characteristics as well as pitch set. As mentioned above, the tone sequences in the present study were composed of the same pitch set but differed in sequence. Considering the tone sequences, characteristics other than pitch set is to be sequential characteristics. More specifically, the sequential characteristics can be considered as some kind of "local" ones, not presently identified, rather than pitch sequence taken as a whole. As we have discussed so far, the results in the present study seem to lead to a speculation that pitch set leads listeners to select several candidates for a final decision of a key, with some "local" sequential characteristics being used to narrow down the number of candidates.

The question arises as to what kinds of sequential characteristics could lead listeners to perceive a key. As mentioned in the Introduction, each of past studies has indicated each of the sequential characteristics, such as specific intervals and specific pitch chromas in particular positions, as additional perceptual cues. However, the past studies examined only the effect of a specific sequential characteristic on key identification, and did not compare the effects of the specific sequential characteristics with those of other sequential characteristics. In other words, whether key identification was more affected by one specific sequential characteristic than by another sequential characteristic has not been demonstrated. To clarify the issue, it will be necessary to identify the relations between many possible sequential characteristics and listeners' key responses, and then to determine what kinds of sequential characteristic most affect the key responses. Following up on this present research, we are currently collecting participants' key responses for numerous number of tone sequences composed of the same pitch set differing in its sequence and analyzing relationships between a relatively large number of sequential characteristics and the participants' key responses (Matsunaga & Abe, 2002, 2004).

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Appendix 1

Tone sequences and the Coeffecients of Concentration of Selections (CCS) by Musicians in Experiment 1

Pitch Set I: 24 tone sequences

	Tone sequence	*CCS* value
I-01	C_4-G_4-E_4-A_4-D_4-B_4 +7, -3, + 5, -7, +9	0.78
I-02	E_4-C_4-B_4-D_4-A_4-G_4 -4, +11, -9, +7, -2	0.72
I-03	A_4-D_4-B_4-C_4-E_4-G_4 -7, +9, -11, +4, +3	0.72
I-04	E_4-G_4-C_4-A_4-B_4-D_4 +3, -7, +9, +2, -9	0.70
I-05	C_4-B_4-D_4-A_4-E_4-G_4 +11, -9, +7, -5, +3	0.64
I-06	G_4-E_4-D_4-A_4-C_4-B_4 -3, -2, +7, -9, +11	0.64
I-07	A_4-B_4-C_4-E_4-G_4-D_4 +2, -11, +4, +3, -5	0.63
I-08	G_4-D_4-A_4-B_4-C_4-E_4 -5, +7, +2, -11, +4	0.61
I-09	D_4-B_4-C_4-E_4-A_4-G_4 +9, -11, +4, +5, -2	0.61
I-10	G_4-A_4-E_4-C_4-B_4-D_4 +2, -5, -4, +11, -9	0.58
I-11	A_4-D_4-E_4-G_4-B_4-C_4 -7, +2, +3, +4, -11	0.57
I-12	C_4-B_4-G_4-E_4-D_4-A_4 +11, -4, -3, -2, +7	0.54
I-13	G_4-A_4-D_4-B_4-C_4-E_4 +2, -7, +9, -11, +4	0.54
I-14	B_4-C_4-A_4-G_4-D_4-E_4 -11, +9, -2, -5, +2	0.52
I-15	B_4-D_4-A_4-E_4-G_4-C_4 -9, +7, -5, +3, -7	0.51
I-16	D_4-G_4-B_4-C_4-A_4-E_4 +5, +4, -1, +9, -5	0.51
I-17	D_4-G_4-E_4-B_4-C_4-A_4 +5, -3, 7, -1, +9	0.50
I-18	A_4-G_4-C_4-B_4-D_4-E_4 -2, -7, +11, -9, +2	0.5
I-19	D_4-A_4-G_4-E_4-C_4-B_4 +7, -2, -3, -4, +11	0.48
I-20	C_4-E_4-A_4-D_4-B_4-G_4 +4, +5, -7, +9, -4	0.48
I-21	A_4-E_4-G_4-C_4-B_4-D_4 -5, +3, -7, +11, -9	0.44
I-22	D_4-A_4-C_4-B_4-G_4-E_4 +7, -9, +1, -4, -3	0.44
I-23	D_4-C_4-B_4-G_4-E_4-A_4 -2, +11, -4, -3, +5	0.38
I-24	B_4-C_4-A_4-D_4-G_4-E_4 -11, +9, -7, +5, -3	0.35

Pitch Set II: 36 tone sequences

	Tone sequence	*CCS* value
II-01	A_4-E_4-C_5-B_4-D_4-G_4 -5, +8, -1, -9, +5	0.77
II-02	C_5-E_4-G_4-A_4-D_4-B_4 -8, +3, +2, -7, +9	0.72
II-03	C_5-D_4-E_4-A_4-G_4-B_4 -10, +2, +5, -2, +4	0.70
II-04	B_4-D_4-A_4-G_4-C_5-E_4 -9, +7, -2, +5, -8	0.64
II-05	A_4-G_4-B_4-D_4-C_5-E_4 -2, +4, -9, +10, -8	0.63
II-06	A_4-D_4-G_4-B_4-C_5-E_4 -7, +5, +4, +1, -8	0.61
II-07	G_4-B_4-C_5-D_4-A_4-E_4 +4, +1, -10, +7, -5	0.59
II-08	E_4-C_5-D_4-B_4-G_4-A_4 +8, -10, +9, -4, +2	0.58
II-09	G_4-E_4-C_5-D_4-B_4-A_4 -3, +8, -10, +9, -2	0.57
II-10	G_4-B_4-D_4-C_5-E_4-A_4 +4, -9, +10, -8 5	0.57
II-11	E_4-G_4-B_4-C_5-A_4-D_4 +3, +4, +1, -3, -7	0.56
II-12	E_4-C_5-B_4-G_4-A_4-D_4 +8, -1, -4, +2, -7	0.54
II-13	A_4-E_4-C_5-D_4-B_4-G_4 -5, +8, -10, +9, -4	0.52
II-14	D_4-A_4-E_4-G_4-B_4-C_5 +7, -5, +3, +4, +1	0.51
II-15	D_4-B_4-C_5-E_4-G_4-A_4 +9, +1, -8, +3, +2	0.50
II-16	G_4-B_4-E_4-C_5-D_4-A_4 +4, -7, +8, -10, +7	0.48
II-17	E_4-G_4-B_4-C_5-D_4-A_4 +3, +4, +, -10, +7	0.48
II-18	A_4-D_4-B_4-C_5-E_4-G_4 -7, +9, +, -8, +3	0.48
II-19	A_4-G_4-E_4-B_4-C_5-D_4 -2, -3, +7, +1, -10	0.47
II-20	B_4-C_5-D_4-G_4-A_4-E_4 +1, -10, +5, +2, -5	0.46
II-21	A_4-D_4-C_5-B_4-G_4-E_4 -7, +10, -1, -4, -3	0.46
II-22	E_4-A_4-D_4-C_5-B_4-G_4 +5, -7, +10, -1, -4	0.44
II-23	E_4-C_5-B_4-D_4-G_4-A_4 +8, -1, -9, +5, +2	0.44
II-24	E_4-A_4-G_4-D_4-C_5-B_4 +5, -2, -5, +10, -1	0.44
II-25	C_5-B_4-G_4-E_4-D_4-A_4 -1, -4, -3, -2, +7	0.44
II-26	B_4-G_4-A_4-E_4-C_5-D_4 -4, +2, -5, +8, -10	0.44
II-27	A_4-B_4-D_4-C_5-E_4-G_4 +2, -9, +10, -8, +3	0.44
II-28	E_4-C_5-A_4-D_4-B_4-G_4 +8, -3, -7, +9, -4	0.44
II-29	G_4-E_4-A_4-C_5-B_4-D_4 -3, +5, +3, -1, -9	0.42
II-30	A_4-B_4-C_5-E_4-G_4-D_4 +2, +1, -8, +3, -5	0.40
II-31	D_4-C_5-E_4-G_4-B_4-A_4 +10, -8, +3, +4, -2	0.40
II-32	D_4-C_5-B_4-G_4-E_4-A_4 +10, -1, -4, -3, +5	0.38
II-33	A_4-E_4-G_4-B_4-D_4-C_5 -5, +3, +4, -9, +10	0.38
II-34	A_4-G_4-E_4-C_5-B_4-D_4 -2, -3, +8, -1, -9	0.37
II-35	D_4-B_4-G_4-A_4-E_4-C_5 +9, -4, +2, -5, +8	0.35
II-36	D_4-C_5-G_4-E_4-B_4-A_4 +10, -5, -3, +7, -2	0.35

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Footnotes

[1]In this paper, we restricted the intervals to "successive intervals".

[2]In this paper, intervals were denoted by positive integers for ascending intervals and by negative integers for descending intervals (one unit = a semitone). For example, the ascending major third and the descending major third were denoted as (+4) and (-4) respectively.

[3](±2), (±3), (±4), (±5), (±7), (±9), and (±11) could be derived from Pitch Set I. (±1), (±2), (±3), (±4), (±5), (±7), (±8), (±9), and (±10) could be derived from Pitch Set II.

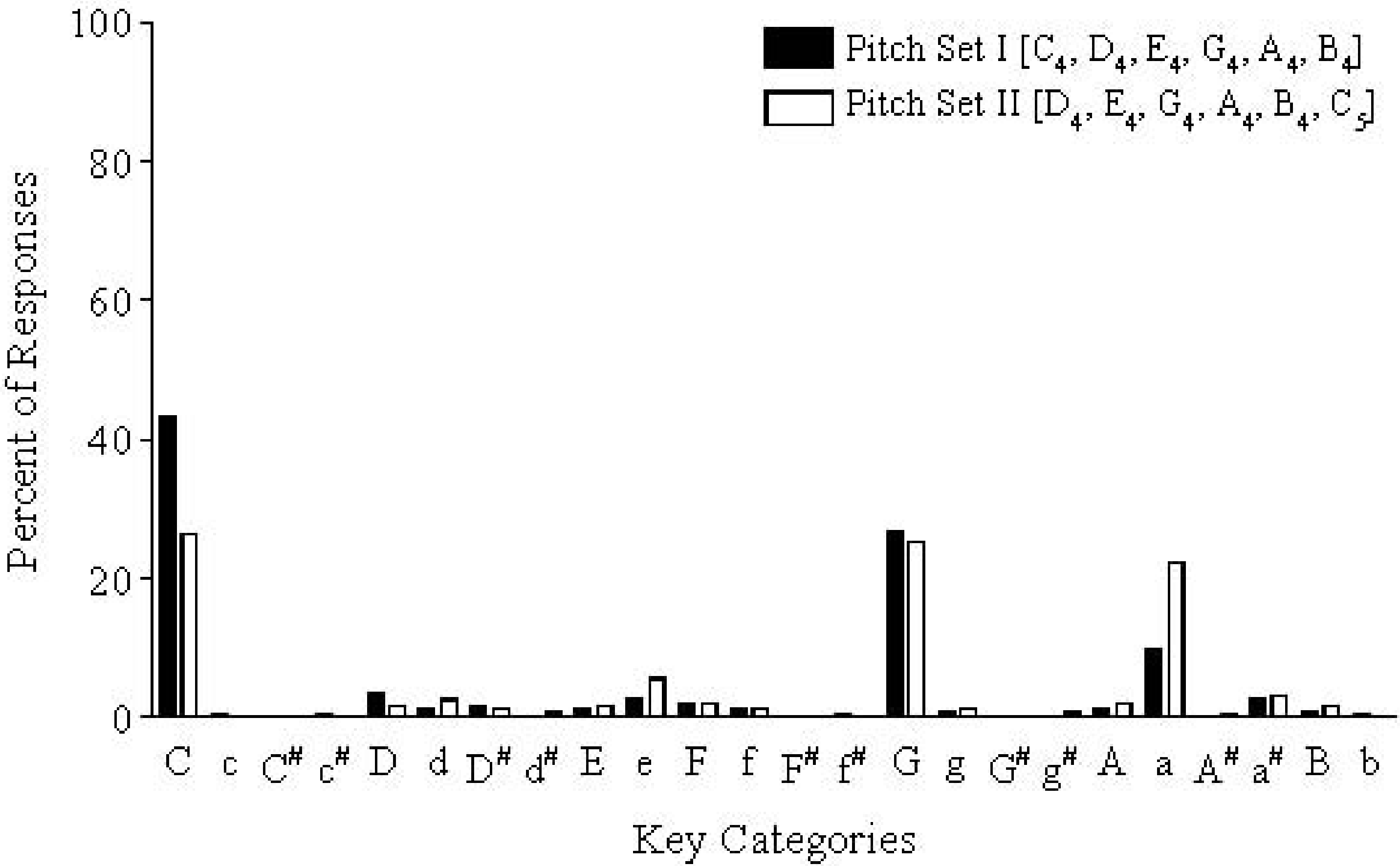
[4]The coefficient of concentration of selection (*CCS*) is calculated by the equation: $CCS = \sqrt{\chi^2 / \{N(K-1)\}}$ (Hoshino & Abe, 1984). *K* is the number of response categories: 24 major and minor key categories in Experiment 1 and 12 tone categories in Experiment 2. *N* is the total number of responses for each tone sequence: 13 in Experiment 1 and 31 in Experiment 2. *CCS* values range from 0 to 1.0, with the highest value indicating that all key/final tone responses are concentrated in only one category.

Figure Captions

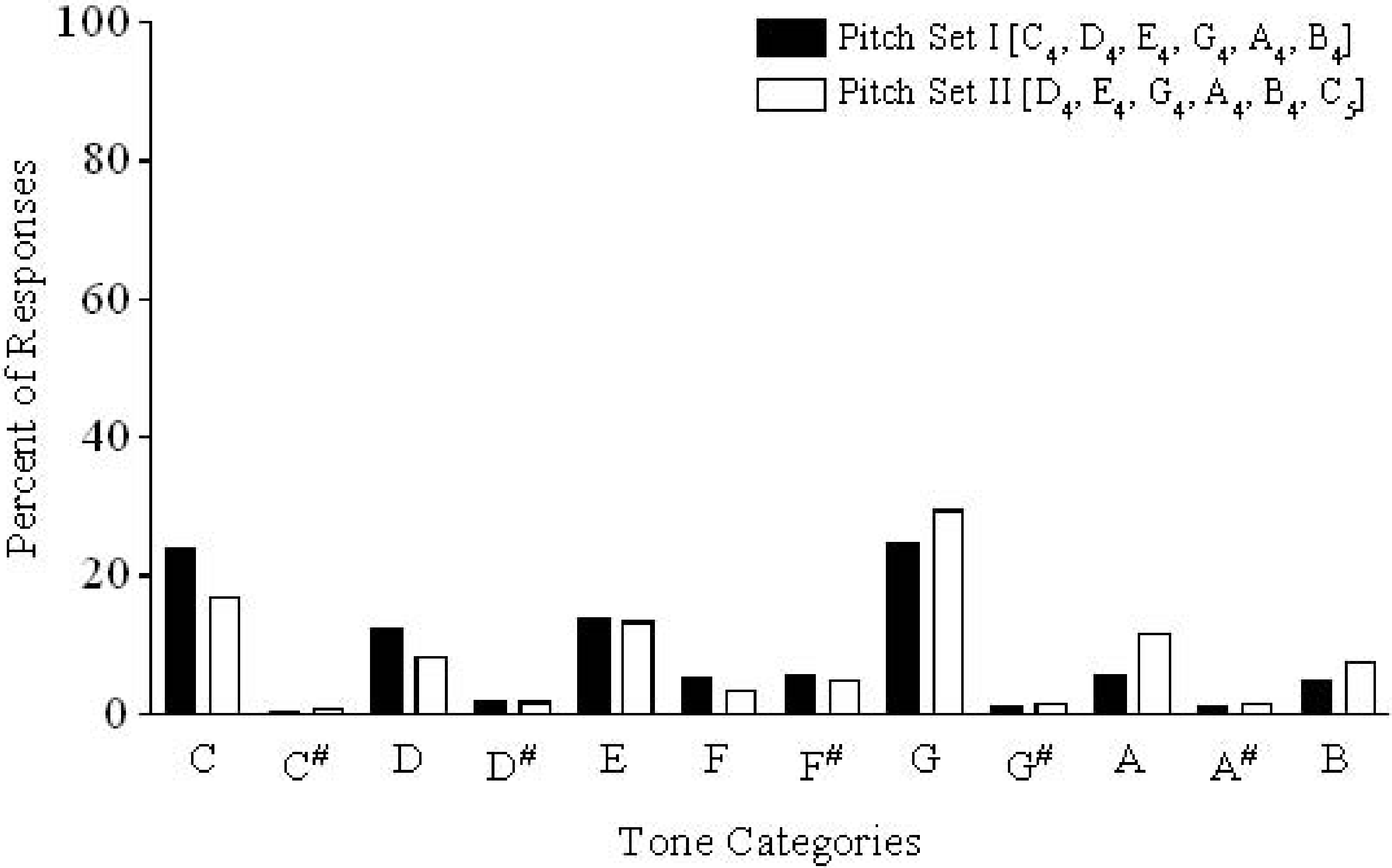
Figure 1. The average key profile for musicians in Experiment 1. Capital letters and small letters denote major and minor keys, respectively.

Figure 2. The average final-tone profile for nonmusicians in Experiment 2.

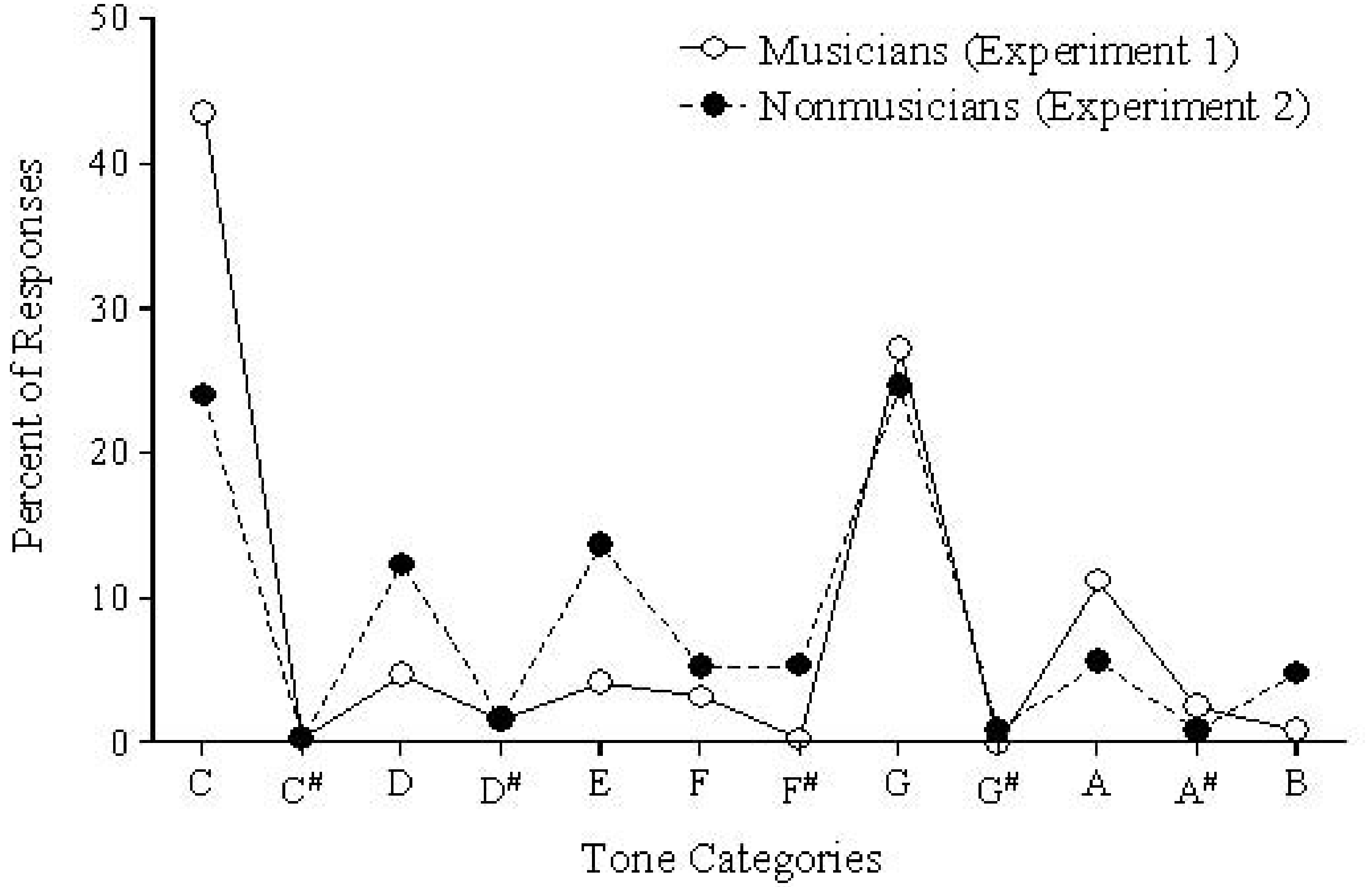
Figure 3. The distribution of responses of musicians and nonmusicians for the 60 tone sequences.



Pitch Set I [C_4, D_4, E_4, G_4, A_4, B_4]
Pitch Set II [D_4, E_4, G_4, A_4, B_4, C_5]
Percent of Responses
100
80
60
40
20
0
C c C# c# D d D# d# E e F f F# f# G g G# g# A a A# a# B b
Key Categories


Pitch Set I [C4, D4, E4, G4, A4, B4]
Pitch Set II [D4, E4, G4, A4, B4, C5]
Percent of Responses
100
80
60
40
20
0
C
C#
D
D#
E
F
F#
G
G#
A
A#
B
Tone Categories

(a) Pitch Set I (24 tone sequences)



(b) Pitch Set II (36 tone sequences)