CATEGORICAL AND LINGUISTIC ASPECTS OF MUSICAL PITCH SPACE

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ABSTRACT

This paper reports on a line of work which is aimed at understanding different aspects of the relationships between spatial cognition and musical cognition. Musicians use spatial language in many ways; one of the most prevalent of these is the mapping of the musical dimension of perceived pitch to a spatial dimension of height.

This study investigated the perceptual nature of c-space (ordinal but unmetered) and p-space (ordinal and metered, but without octave equivalence).

Participants heard eleven different pitches, evenly spread over more than four octaves, each presented in three different timbres. Each pitch was categorized verbally as to a register (low, medium low, medium, medium high, or high), and made a graphic estimation of the placement of the tone within the overall pitch range on a continuous line.

Responses show that perception of even such random stimuli is ordinal, only moderately affected by timbre, and is surprisingly metric. Categorization of the responses shows systematic deviations from linearity, corresponding to a bias to separate pitches into categories of low, medium, and high. Parallels between these responses and studies in visual perception are posed.

1. BACKGROUND

The fields of music cognition and music theory have long used spatial or geometric representations for a variety of phenomena related to musical pitch. Some of the best-known of these efforts would be those of Krumhansl and Shepard (for example, Krumhansl & Shepard 1979, Krumhansl 1990), but also include other approaches (cf. Stevens, Volkmann, & Newman 1937). For the most part these efforts have dealt with representations that operate within a pitch system using octave equivalence, in which pitch height and pitch chroma are treated as (at least partially) separable dimensions. Music theorists have dealt with the notion of pitch height in a variety of ways. One of the most sophisticated, and well-developed, stems from the work of Robert Morris. In his 1984 treatise (Morris 1984, Ch. 2), he defines three kinds of musical spaces: *contour space*, or *c-space*; *pitch-space*, or *p-space*, and *pitch-class space*, or *pc-space*. Briefly, the characteristics of each of these are:

- in c-space, musical events [e.g. notes] are ordered with respect to pitch height or register, but the distances between them are unmeasured except by the number of items in the space from one event to the next; direction from one event to another is 'up' or 'down.' Thus, c-space is ordinal, linear, and unmetric.
- in p-space, musical events are ordered with respect to pitch height, and distances between them are measured in terms of some constant unit, such as the semitone. Distances are calculated in terms of the number of these units, prefixed by a sign to show movement up or down, and there are no octave equivalences. Thus, p-space is ordinal, linear, and metric.
- in pc-space, musical events are mapped onto a cyclically recurring pattern; the examples given replicate the usual concepts of pitch chroma and octave. Distances between events are calculated cyclically, for example modulo the number of chroma in the octave (for Morris, this is usually 12). Thus, pc-space is ordinal, cyclic, and metric.

2. AIMS

This study begins by asking whether the categories of c-space and p-space have any perceptual relevance or are purely rational, theoretic constructs. The questions to be addressed are, first, does an ordinal but unmetered space, like Morris' c-space, seem to be a cognitive representation used by musicians? Second, is an ordinal and metered space, such as p-space, seem to be such a cognitive representation? Third, is there a categorical structure to the cognitive representations of pitch space, or are these representations continuous rather than categorical? Finally, to what degree do verbalizations about pitch spaces represent the internal representations of these spaces?

In considering these questions, we were also interested in the question of whether musical pitch-space has perceptual and representational features like those found in visual space. We were interested specifically in a number of findings related to visual spaces, those described in the work of Huttenlocher and her colleagues (Crawford, Rieger, & Huttenlocher 2000, Newcombe & Huttenlocher 2000, Huttenlocher, Newcombe, & Sandberg 1994). In these, visual space as represented in children and adults has both a continuous and a hierachical-categorical aspect, and judgments of distance and placement of objects within a visual field show systematic deviations from linearity. In addition, the verbal encodings used to describe visual space differ from continuous responses. We sought to begin investigating to what degree phenomena such as these might be paralleled in the auditory domain of pitch height.

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3. METHOD

3.1. Equipment

All stimuli were produced and played on an Apple Macintosh iBook computer. Initial stimuli were produced using a MIDI sequencing program (FreeStyle), and played back using QuickTime's General MIDI timbres. These stimuli were converted to individual pitches and stored as SoundEdit format files (16 bit, 22.05KHz sampling rate, monaural). Presentation of stimuli and collection of data was carried out with the PsyScope experiment-management software package. All stimuli were played in a sound-attenuating booth over Alesis Point 7 speakers, at a comfortable volume level. Statistical analyses were carried out using the JMP software package.

3.2. Stimuli

A set of 33 pitches comprised the stimulus set. The goal was to have evenly-spaced pitches covering a wide range, within defined extremes of high and low. Extremes of register were set as F0 and F6. The distance between the extreme pitches is 84 semitones. The experimental stimuli used the eleven pitch-classes remaining once F-natural was removed from the complete chromatic collection. These eleven pitch-classes were deployed in a manner designed to cover a wide range as evenly as possible, use all eleven elements, and avoid any possible tonal references which could skew a perception of registral distance by conflating it with tonal distance. The set of tones was: (D1, G#1, C#2, G2, C3, F#3, B3, E4, A#4, D#5, A5). The distance between each adjacent pair of pitches in this series, in semitones, is (6, 5, 6, 5, 6, 5, 5, 6, 5, 6, 5), roughly alternating intervals of the perfect fourth and the tritone. The series of pitches falls closer to the upper boundary of F6 (8 semitones away) than the lower boundary (21 semitones), biasing toward what was taken to be a more 'normal' musical registral distribution.

Three different timbres were used for presentation of the eleven pitches, in order to investigate the possible influence of timbre on perceptions of pitch space. These timbres were QuickTime's General MIDI Whistle, Tuba, and Woodblock. The Whistle timbre is notably free of upper partials, and thereby very closely approximates a sine wave in steady-state; the instrument does, however, use vibrato. The rate of vibrato does not differ noticeably in different registers and is not, therefore, a clue to registral placement. The Tuba timbre is notably brasslike, although the instrument may variably be identified as a trombone or trumpet depending on register. Vibrato is present in this timbre, as in the Whistle. The Woodblock sound has a distinctive 'woodlike' character in middle and upper registers, and in the lower registers has a sound more like a drum with a loosely tuned head. In all registers it is notably percussive, with a less-clearly-defined projection of a specific pitch and a less-sustaining envelope than the other sounds. There is no vibrato on this timbre.

3.3. Participants

10 advanced students in music from Northwestern University served as participants. All were volunteers and were not compensated for their participation. Music students were used to ensure that the task (assigning pitches to registers by category and by a continuous response) would pose no conceptual difficulties (all participants reported that the task was clear and meaningful). The mean age of the participants was 25.2 years, with a mean of 18.8 years of formal musical training. All participants were native speakers of English, and none possessed absolute pitch.

3.4. Procedure

Participants were instructed that they would hear a series of pitches in randomly assigned registers. Their task was to categorize each pitch as low, medium low, medium, medium high, or high, and also to click with the mouse on a vertical line drawn on the computer screen (360 pixels in length) to show their estimate of the relative height of the pitch, with the bottom of the line being the 'floor' of the registral possibilities and the top of the line being the 'ceiling.' When the mouse was clicked, the next tone would be played and the next response collected. In order to give a context for the extremes of register, the pitches F0 and F6 were played twice, using the Whistle timbre, as examples of the bottom and top of the range to be used.

Each of the eleven stimulus pitches was played three times, once for each of the timbres used. The ordering of these thirty-three pitches was randomized, so that registers and timbres could freely intermingle. Responses on the categorical judgments were recorded on paper by the experimenter, and the mouse click positions on the continuous judgments were recorded by PsyScope. The experimental session lasted between seven and ten minutes.

4. RESULTS

Question one: is pitch-space ordinal? the answer to this question with regard to the materials and task employed in this experiment is "yes, " both in the categorization and continuous judgment tasks. Figure 1 shows the categorical judgments for each of the three timbres, relative to the registrally-ordinal positions of the pitches. Within each condition, all three conditions prove to be monotonically ascending with regard to ordinality. Thus, in the task used here, listeners' collective judgments of ordinality is strong and independent of timbre. The question is more complicated when the results of in one timbre are compared with another. The same ordinal element (with the same fundamental frequency) Thus, the findings on this task indicate that, at least for these participants, pitch-space is largely ordinal, providing empirical support for the theoretical construct of c-space.

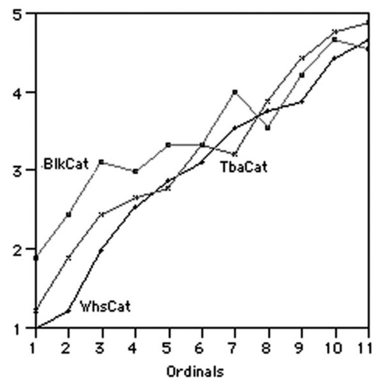

Figure 1: Categorical judgments of pitches, by timbre, plotted against ordinal registral positions

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Question two: is pitch-space metered? the answer to this question, with regard to this task and these participants, is a somewhat surprising “yes.” Figure 2 shows the results of regression analyses carried out on the continuous judgment responses in this experiment. In all cases the fit to the line is quite high (r-squares of .83. .87, and .52, respectively, p<.001), when mapped from the location on the line relative to the placement of the pitch in p-space, measured as a number of semitones from the ‘floor’ of F0.

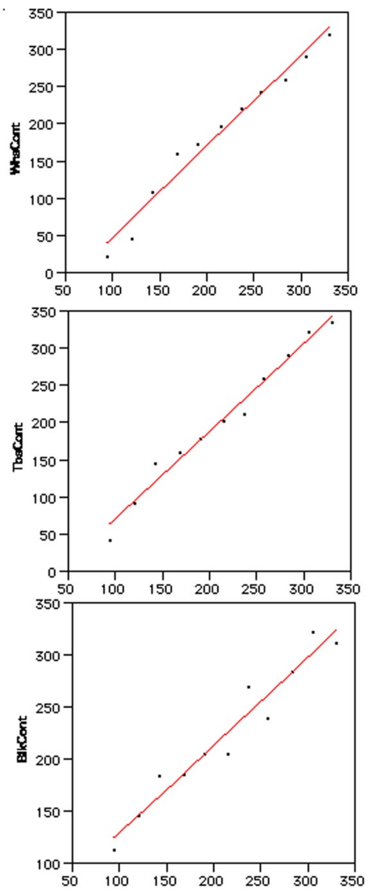

Figure 2: Regression analyses for continuous judgements, by timbre (Whistle, top; Tuba, center; Woodblock, bottom)

Question three: do judgments about pitch-space display the kind of systematic distortions found in studies of adults’ and childrens’ judgments about visual space? The answer seems to be “somewhat.” This was a bit surprising, given that the visual impression of the regression analyses performed on the continuous judgment data is that a more complicated function, such as a third-order polynomial, would provide a better fit to the data. However, this is apparently not the case, as the added parameters of the polynomial functions are not statistically significant. Additional analyses performed on the direction and magnitude of the errors from their “veridical” positions show that these errors can be modeled to some degree by linear or polynomial functions, but no truly systematic element is apparent at the time of this writing.

Question four: does perception of pitch-space have categorical in addition to ordinal and metric aspects? The answer seems to be “yes, ” but the results are rather modest in that regard. Figure 3 shows the results of cluster analyses of both the categorical and continuous judgments, combined across timbres. The primary results to be seen are that extremes of register--the lowest and highest pair of pitches—segregate out, and the middle ranges are more complex. Boundaries between the five registral categories used here may be less salient in the middle register, whereas the outlying notes at the extremes are easily categorized as low and high. The materials used in this study may simply have too coarse a grain over the registers used to allow any finer categories to be discerned.

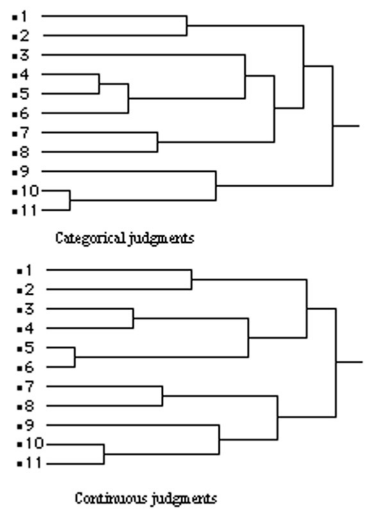

Figure 3: Cluster analyses, combined across timbres, for categorical judgments (top) and continous judgments (bottom)

Question five: does timbre influence perception of elements in pitch space? the answer is a qualified “yes.” Complexity of timbre is implicated in the results seen in Fig. 1, where the simplest sound--the Whistle instrument--produces the most linear results, and the most complicated sound--the Woodblock instrument--produces the most nonmonotonic results. The Woodblock sound behaves very differently over the registers used in this study, sounding like really different kinds of instruments (membranophone vs. idiophone). Given the complicated behavior of this timbre, it is difficult to generalize from the results presented here, but the tendency for the perceived height of the percussive sounds to be shifted upwards in absolute terms relative to the Whistle or Tuba sounds opens up further questions for systematic investigation.

5. CONCLUSIONS

A number of issues remain to be considered. First, one wonders how these results might have come about in terms of either developmental processes or the acquisition of musical skill. At the time of this writing (March 2003) we are planning, but have not yet undertaken, studies with children and with adults with no formal musical training. By dealing with these groups of participants we hope to see what developmental or training

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factors may help to explain our current results, especially those related to the highly accurate metering of p-space. We are curious to see what happens in these populations; for example, if ordinal representations (c-space) remain but metric ones (p-space) weaken. A second main set of issues to be explored surround the relationship of c-space and p-space perception to pc-space, where octave equivalence comes into play. It seems to be the case that octave confusions occur rather regularly in musical experience, and it is possible that pc-space interacts with p-space in complicated ways.

6. REFERENCES

1. Crawford, L.E., Regier, T, and Huttenlocher, J. (2000). Linguistic and non-linguistic spatial categorization. *Cognition* (75), 209-235.

2. Huttenlocher, J., Newcombe, N., & Sandberg, E. (1994). The coding of spatial location in young children. *Cognitive Psychology* 27, 115-147.

3. Krumhansl. C. (1990). *Cognitive Foundations of Musical Pitch*. Oxford: Oxford University Press.

4. Krumhansl, C., & Shepard, R. (1979). Quantification of the hierarchy of tonal functions within a diatonic context. *Journal of Experimental Psychology: Human Perception and Performance*, 5, 579-594.

5. Morris, R. (1984). *Composition with pitch classes: A theory of compositional design*. New Haven: Yale University Press.

6. Newcombe, N.S., and Huttenlocher, J. (2000). *Making space: The development of spatial representation and reasoning*. Cambridge, Massachusetts: MIT Press.

7. Stevens, S. S., Volkmann, J., & Newman, E.B. (1937). A scale for the measurement of the psychological magnitude pitch. *Journal of the Acoustical Society of America*, 8, 185-190.

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