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MULTIDIMENSIONAL SCALING OF MAJOR AND MINOR
TRIADS: AURAL IMAGERY AND DIRECT PERCEPTION

Thesis for the Degree of M. A.

MICHIGAN STATE UNIVERSITY

CYNTHIA H. NULL

1972

THESIS



ABSTRACT

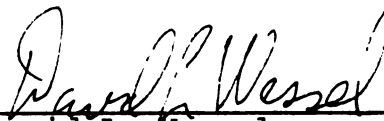
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By

Cynthia H. Null

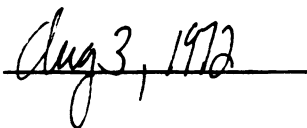
Using the method of triadic comparisons, five musicians made similarity judgments between eight musical triads under both imagined and heard conditions. In the imagined condition, the subjects were instructed to imagine the sound of the triads and in the heard, the triads were played on a well tuned piano. Multidimensional scaling (INDSCAL & M-D-SCAL) of the similarity data provided dimensional representations possessing convincing musical interpretations. For two of the subjects, the imagined and heard judgments appeared to be generated from the same underlying structure suggesting that these composers used veridical images. For the remaining subjects discrepancies between the imagined and heard data were noted. The data structures appear useful as a basis for educating the musical imagination.

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A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

MASTER OF ARTS

Department of Psychology

1972

To Tim

ACKNOWLEDGMENTS

I would like to express my appreciation to Dr. Charles F. Wrigley and Dr. Lester M. Hyman for serving as members of my thesis committee. I am especially grateful to Dr. David L. Wessel, my committee chairman and advisor, for his inestimable assistance in all phases of this research.

A special thanks goes to my husband for long lasting patience, understanding, and encouragement.

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INTRODUCTION

Composers have often remarked that auditory imagery is essential to the act of creating music. In one of Mozart's letters we find "nor do I hear in my imagination the parts successively, but I hear them, as it were, all at once. What a delight this is I cannot tell! All this inventing, this producing, takes place in a pleasing, lively dream" (Holmes, 1845).

The composer relies upon the veridicality of his imagination. If his musical imagination is to be effective what he hears in his mind's ear must bear a close resemblance to the actual sound of the musical performance. In other words, we might say that when the imagination is veridical there is a kind of isomorphism between the aural image and the perceptual consequence of direct contact with the sound source.

One such concept of isomorphism supposes that for each external event there is an internal representation. That is, in saying the word violin one also "hears" or "sees" a violin. This concrete type of structural isomorphism was discredited by Skinner (1945, 1963) and Wittgenstein (1953) by pointing out that one can learn the appropriate use of words like "violin" without access

to any internal representation of a violin. Actually, if there is any internal event which corresponds to our perception of a violin sound it need only have a causal relationship to the word "violin." A structural isomorphism is not required and in fact the logic surrounding such a concept might well lead to the notion of neurons that vibrate in accord with the string equations.

In an attempt to salvage this idea of isomorphism between the external world and internal representations, Shepard (1968, Shepard and Chipman, 1970) has proposed a second-order relationship among various external objects and corresponding internal representations. This relationship is sought between a set of potential stimuli and the set of their corresponding internal representations instead of between a single stimulus and its corresponding representation.

To illustrate a second-order isomorphism, Shepard and Chipman (1970) studied the relationship between similarities in shapes of states determined by looking at actual outlines of the states and imagining the shape. The similarity data for each subject were analysed using a nonmetric multidimensional scaling technique. The configurations for the two conditions were compared by a least squares method for orthogonal rotation to congruence. There was no appreciable systematic difference between seeing and imagining the shapes of the states

involved. There was strong evidence to support the hypothesis that the judgments under both conditions were based upon geometric properties of the states.

The following experiment is intended to assess the extent to which there is a second-order isomorphism between internal representations of sound and the corresponding representations of direct perception and the extent to which these internal relations parallel physical qualities of the sounds and music theory.

Shepard and Chipman (1970) used a ranking of all possible pairs of stimuli for collecting and dissimilarity data for both conditions. A rank order of the pairs is not possible for the listening condition. There is no convenient way for the subject to have all possible pairs available. Therefore, a method compatible for both the "imagined" and "heard" conditions is necessary.

The method of triadic comparisons was used in one "imagined" and the "heard" sessions. This method was chosen because of its nonverbal character. Subjects may be unable to indicate anything significant about the structure of mental images but can make judgments about relations between these images. The subject was asked to pick the two most similar sounding chords and the two most dissimilar sounding chords among three presented. The second "imagined" session consisted of the subject putting the pairs of stimuli in a rank order in terms of aural similarity.

METHOD

Subjects

Three music graduate students majoring in composition and two faculty composers served as subjects.

Stimuli

The stimuli, shown in Fig. 1, were four major and four minor triads. These chords were in root position and each triad had its relative minor triad included in the set

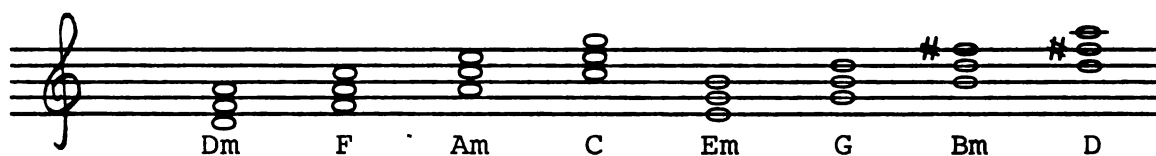


Figure 1. The eight chords

(C, Am, F, Dm, G, Em, D, Bm). The notes in the chords ranged in frequency from 293 to 784 Hz. The 56 sets of all possible combinations of three chords appeared in random order on one page of staff paper. The order within each triple of chords was also random. The 28 sets of all possible pairs of chords were written on separate 4" X 6" unlined cards. The order within each pair was random. The audio stimuli were played on a well tuned piano.

Procedure

This experiment required three sessions spaced at a minimum interval of seven days. During the first session the subject was given the 56 sets of three chords. For each triple of chords the subject was asked to imagine the sound of each chord and decide which two chords sound most similar and which two sound most dissimilar. This technique is commonly called triadic comparisons (Plomp, 1969). The reader should take care not to confuse the similarity judgment procedure (triadic comparison) with the stimuli (major and minor triads). The responses were marked by the subject on the staff paper by circling the two chords sounding most similar and underlining the two sounding most dissimilar. A dissimilarity matrix was tabulated for each subject by cumulating the scores for each of the 28 pairs. For a given triple a score of "0" was assigned to the pair judged most similar, a score of "1" to the intermediate pair, and a "2" to the pair judged most dissimilar.

During the second session the subject arranged the 28 pairs of written chords in a rank order with the pair sounding most similar on top followed by the next most similar pair and so on with the most dissimilar sounding pair at the bottom. The subject was again instructed to imagine the sound of the chords and then make the ranking. The cells of the dissimilarity matrix for each subject were filled with the rank number of each pair.

During the final session triadic comparisons like those in the first session were made, but this time the chords were played on a piano. The three possible pairs for each triple were first played in a random order. The subject could request any or all of the pairs to be repeated. He was instructed to listen until he could decide which pair was most similar and which was most dissimilar. A dissimilarity matrix was formed as before.

RESULTS

There are two major issues to be considered. First, were the judgments of dissimilarity of sound the same for both the "imagined" and "heard" triadic comparisons? Second, how well did the sets of judgments parallel physical qualities of the chords and musical theory? Also of interest is whether the two written sessions yielded similar results.

An overall comparison of the written and audio triadic comparison sessions was made by forming an average matrix for each condition. Because of the difference between individual subjects, the matrices did not extend the full possible range of 0 to 12. The two matrices do seem related to each other, in that, the most dissimilar pair for both was F major and B minor. The most similar pair for the audio condition was C major and F major which was the second most similar pair for the written condition. The product-moment correlation coefficient between the 28 average values was $+ .74$.

To investigate further the relationship between these two conditions, product-moment correlations were computed among all ten dissimilarity matrices (2 for each of five subjects) as well as between these individual

subject matrices and two average matrices considered above. These results are summarized in Tables 1 and 2.

In Table 1, Column A is the correlation between the individual written triadic comparisons and the individual audio comparisons. The subjects are arranged in order of this value from "best" to "worst". The correlations between individual data and the corresponding group data for both conditions are presented in Columns B and C. Columns D and E give the correlation values for the individual matrices to the opposite conditions group matrix.

Shepard and Chipman (1970) found that their subjects were either always high or always low in all of these correlational values. This is not the case for these data. Subject JP, for example, is low as far as consistency with himself on the two conditions (Column A) but is the highest as far as his written judgments compared to the average audio data (Column D). DS is the most consistent with himself on the two conditions (Column A) but is low as far as his written data compared to the average audio data and his audio data compared to the average written data (Columns D and E, respectively). However, TP is the lowest in all conditions except consistency with the group written condition where he is just above the lowest value.

The values in Columns B and C are inflated by the contribution the individual subject's data makes to the group data. The values in Table 2 are an effort to free

Table 1

Measures of Correlation Between "Imagined" and "Heard" Conditions
(presented for individual composers and for the group of five as a whole)

	A individual "imagined" vs. individual "heard"	B consistency with group		D individual "imagined" vs. group "heard"	E individual "heard" vs. group "imagined"	F consistency with 2-dim INDSCAL model	G "heard"
		"imagined"	"heard"			"imagined"	
DS	.60	.89	.79	.71	.47	.82	.81
TL	.51	.86	.67	.46	.64	.93	.74
AF	.47	.69	.76	.81	.64	.90	.78
JP	.37	.88	.63	.78	.43	.82	.60
TP	-.12	.70	-.30	.22	-.34	.91	.26
median	.47	.86	.67	.71	.47	.90	.74
mean	.37	.80	.51	.60	.37	.88	.64

Group "imagined" vs. group "heard" = .74

Table 2

Measures of Central Tendency and Dispersion of the Distribution of all Correlations Between Individual Dissimilarity Data for Each Possible Combination of Conditions^a

	Without TP							
	A median	B mean	C sd	D N	E median	F mean	G sd	H N
1. one S's "imagined" vs. other S's "imagined"	.61	.56	.24	10	.67	.64	.18	6
2. one S's "heard" vs. other S's "heard"	.20	.09	.37	10	.39	.37	.12	6
3. combined 1 and 2	.41	.33	.30	20	.47	.51	.15	12
4. one S's "imagined" vs. other S's "heard"	.42	.27	.37	20	.51	.51	.20	12
5. one S's "imagined" vs. same S's "heard"	.47	.37	.28	5	.49	.49	.10	4

^a ("imagined" - "imagined," "heard" - "heard" and "imagined" - "heard")

the comparisons of this contamination. Column A and B present the mean and median of all correlations between individual dissimilarity values as specified at the left of the table. The standard deviation of the distribution of included correlations and the number of correlations considered are given in Columns C and D. Columns E through H contain the same information as A through D except subject TP has been eliminated since he was most inconsistent with himself and the grouped data.

It is apparent that, on the average (Columns A & B), there is more agreement between subjects under the "imagined" condition (Row 1) than under the "heard" condition (Row 2). This is less true when subject TP is eliminated (Columns E & F). This difference could indicate that the judgments were generally more variable under the listening condition. Also note that subjects tend to agree with themselves (Row 5) under the two conditions to the same degree that they agree with each other (Row 4). These correlations should be kept in mind for comparison with the multidimensional scaling analysis.

To investigate how subject's judgments are related to physical properties of the chords, the data were analysed using two multidimensional scaling techniques. The matrix entries were treated as distances and each matrix was submitted separately to the Shepard-Kruskal nonmetric scaling algorithm (Shepard, 1962a & b, Kruskal, 1964a & b), specifically, Kruskal's "M-D-SCAL" (stress formula 1).

M-D-SCAL solutions were found for all ten subject matrices. The only solutions with low enough stress values to be considered (Klahr, 1969) were those for the "imagined" condition. In Figures 2 and 3 are examples of the two types of solutions determined by M-D-SCAL. The solution for AF (Fig. 3) shows a circular pattern. For subject TL (Fig. 2) comparisons between the stimuli seem to be made using the distinction major or minor.

In situations where nonmetric scaling programs like M-D-SCAL fail to find meaningful solutions, an individual differences scaling technique developed by Carroll and Chang (1969) called "INDSCAL" has been useful. This metric analysis is more robust in that it takes advantage of the commonalities among subjects. All ten matrices were submitted simultaneously to this multidimensional scaling technique. This method assumes individuals are differentially weighting the dimensions of a common Euclidean "psychological space." The distance estimates are converted for each subject into pseudo-distance scalar product matrices using Torgerson's procedures (1958). Using a generalization of the "Eckart-Young Theorem" to decompose these three-way tables of scalar products between stimuli, this program yields both a group stimulus space with a unique set of dimensions and a subject space showing how each subject weighted the dimensions in the stimulus space. Columns E and F in Table 1 present the correlations between the individual subject's scalar products matrix and his weighted INDSCAL two dimensional solution.



Figure 2. Two dimensional M-D-SCAL plot of subject TL's
"imagined" triadic comparison data with stress
(formula #1) = .008

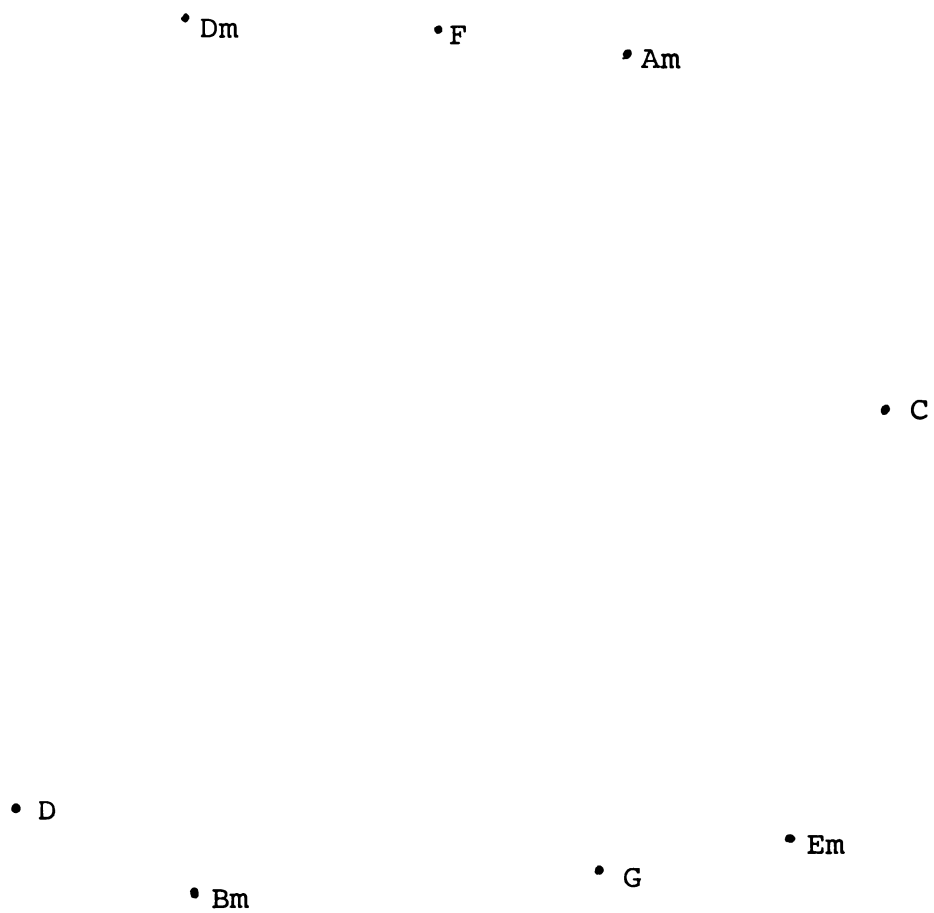


Figure 3. Two dimensional M-D-SCAL plot of subject AF's "imagined" triadic comparison data with stress (formula #1) = .091

The group stimulus space appears in Figure 4. The dimensions seem to be major-minor and pitch level by fifths, that is, the chords are related in that each is a fifth above the one next to it, after an octave change for chords Em, Bm, G, and D (G is a fifth above C and a fifth below D). The octave change is a common musical transformation which leaves the pitch relationships unchanged. The overall correlation coefficient between the ten scalar products matrices and their weighted two-dimensional INDSCAL solution was +.78.

The subject space is shown in Figure 5. The distance from the origin indicates how well a subject's data are accounted for by the dimensions of the group space. A subject's personal space can be determined by applying the weights as defined by the subject to the group stimulus coordinates (for example, for TP's written condition, the fifth dimension is hardly used so the plot would look like two clusters of major and minor triads). Note that for the audio condition TP has a negative weight on the fifth dimension. This indicates that this two dimensional model is systematically violated by this subject. Subjects JP and DS seem to have used the dimensions in a similar manner for both audio and written conditions.

The M-D-SCAL solution for subject TL compares well with the INDSCAL solution (see Fig. 2). The two dimensional plot for subject AF does not compare to the INDSCAL plot

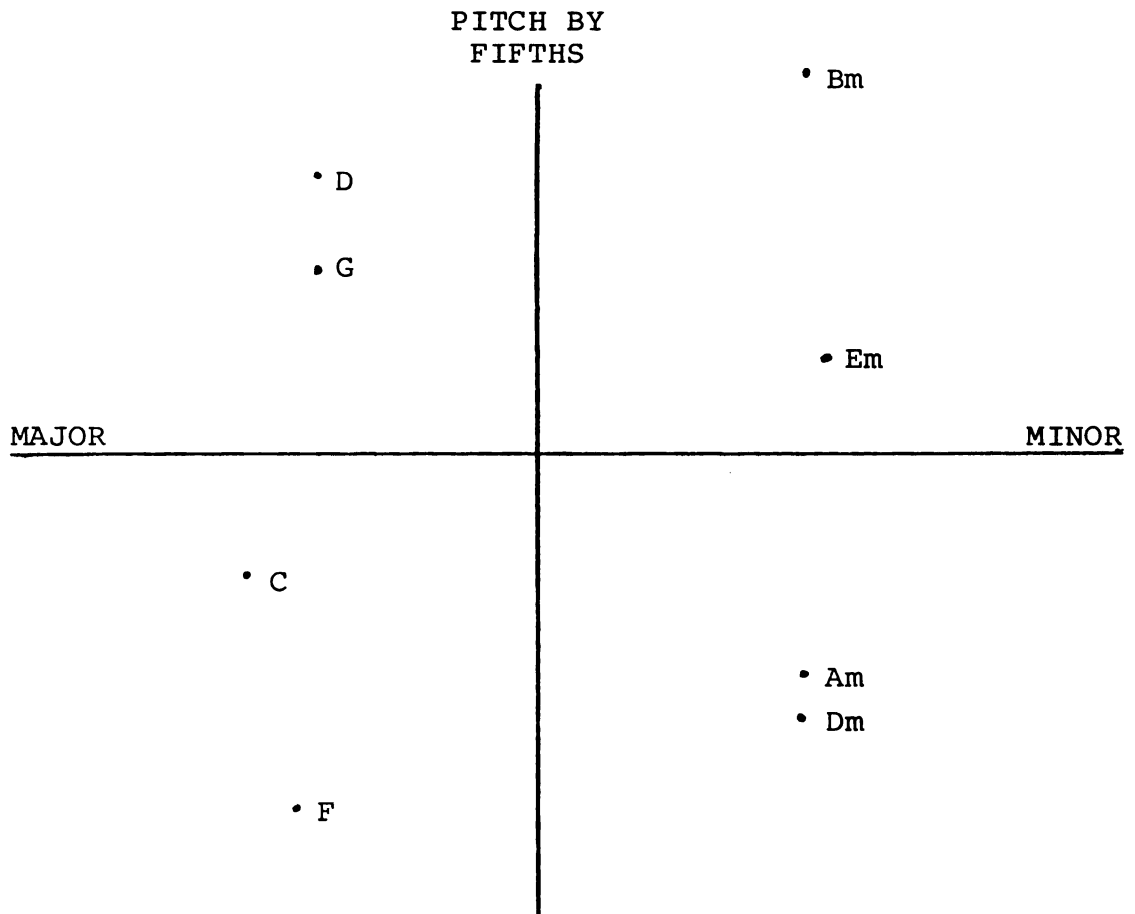


Figure 4. Two dimensional INDSCAL group stimulus space for "imagined" and "heard" triadic comparison data with an overall correlation of .78.

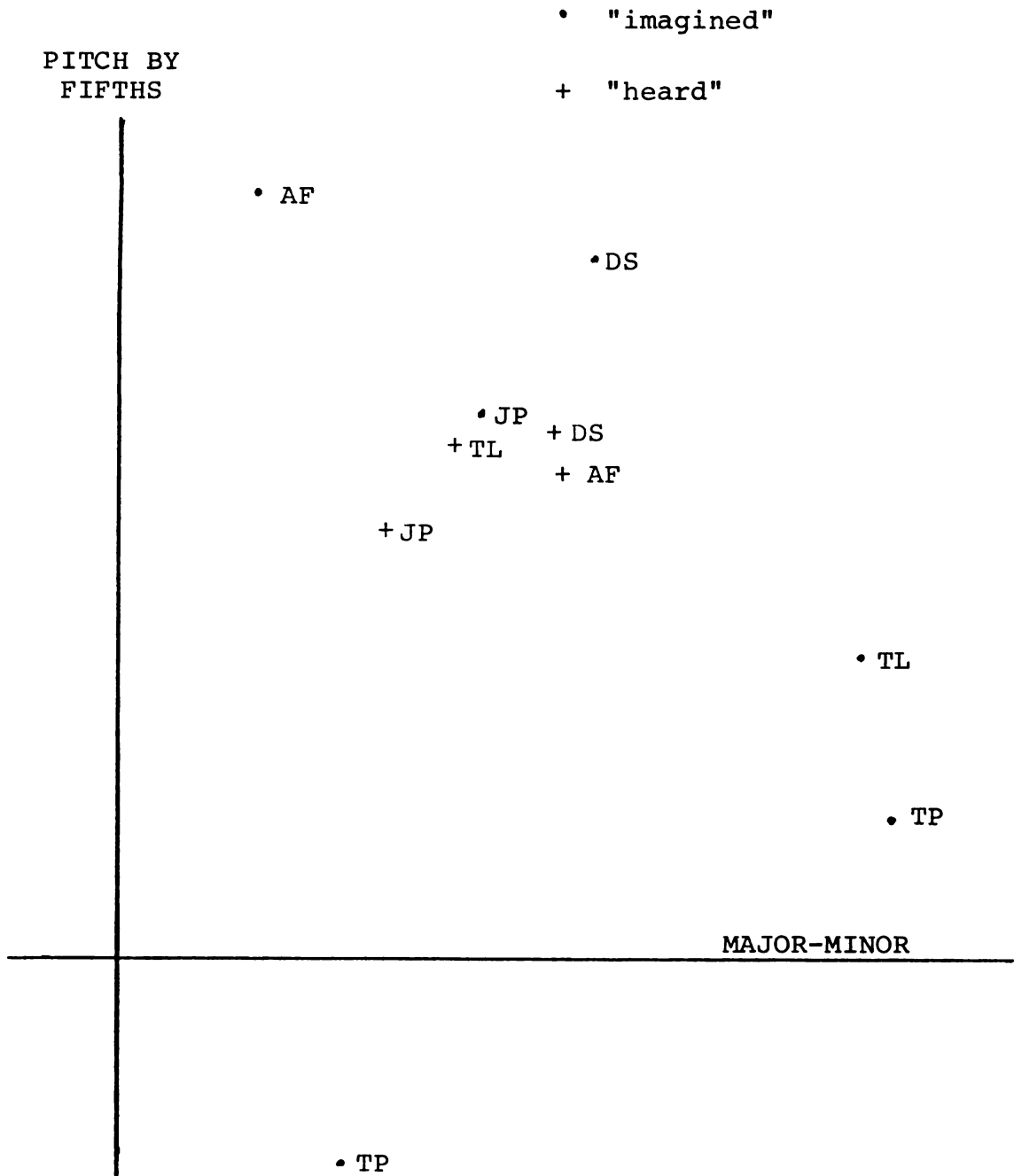


Figure 5. Two dimensional INDSCAL subject space for "imagined" and "heard" triadic comparisons data

favorably (see Fig. 3). This circular pattern cannot be averaged with the previous solution to form one two-dimensional plot. That is, this pattern cannot be formed by weighting the orthogonal major-minor and pitch order by fifths dimensions. This leads to the question of how appropriate the INDSCAL solution is for this set of data. These two solutions seem to be compatible; yet the subject space indicates that the written data for AF is explained to a great extent by the dimension "fifth." The AF solution should then be a column of chords in pairs, F major-D minor followed by C major-A minor, etc.

The data for the ranking of pairs in the imagined condition were analyzed in a similar way. Correlation coefficients were determined between the average ranking and the average written and the average audio conditions. These values were +.82 and +.71, respectively.

In Table 3 are the other correlation values between the individual pairs data and individual written triads, individual audio triads, group pairs, group written triads and group audio data. The most interesting is Column E. The consistency with the group pairs data is much lower for the other two conditions (Cols. B and C of Table 1). This indicates the subjects differed in judgments made under this condition. By comparing the ranked data to the triadic data for the written condition a substantial difference is seen between subjects. In looking at the two dimensional

Table 3
Measures of Correlation Between "Paired" and "Imagined" and "Heard" Conditions
(presented for individual composers)

	A individual "paired" vs. individual "heard"	B individual "paired" vs. individual "imagined"	C individual "paired" vs. group "heard"	D individual "paired" vs. group "imagined"	E individual "paired" vs. group "paired"
TL	.75	.63	.58	.75	.84
DS	.72	.84	.66	.61	.77
AF	.51	.01	.28	.59	.56
JP	.18	.56	.53	.50	.70
TP	-.12	.24	.27	.21	.44
median	.51	.56	.53	.59	.70
mean	.41	.45	.46	.53	.66

Group "paired" vs. group "heard" = .71

Group "paired" vs. group "imagined" = .82

M-D-SCAL plots for subject AF both patterns discussed above were found. For the written triads condition the circular pattern was found but for the ranking of pairs the solution relied almost entirely on the major-minor dimension. This holds for other subjects but not as strongly. It seems that the subjects were attending to the task differently in the two "imagined" conditions.

DISCUSSION

The correlation coefficients in Tables 1 and 2 fail to indicate a perfect relationship between the dissimilarity judgments in the "heard" and "imagined" conditions. Does this implicate differing underlying cognitive structures for the two conditions or is it that both sets of judgments are noisy reflections of the same underlying structure?

Unfortunately the M-D-SCAL solutions with their poor fit to the data offer little assistance in pinning the judgments to the same structure. The INDSCAL solutions, however, shown in Figures 4 and 5 offer a comprehensible picture of the data. First, it provides an answer to the question posed above. Some subjects imagine the way they hear (DS and JP), others don't (AF, TL, and TP). Second, the INDSCAL solution has a convincing music theoretic interpretation.

Although two of the subjects appear to have veridical imaginations, what can be concluded about the other three? One possibility is that their images are based on the visual representation of the stimuli. The extent of this visual contamination could be gaged by running musically naive subjects on a visual comparison task and by running experienced subjects where the visual display would have no influence, such as having the chords in different

octaves or the notes in the chords in different octaves. It could be that these subjects do not have veridical imaginations. If they do not, by knowing where they are in the subject space, they could learn what other dimensions they should be attending to so as to make their imaginations match their perceptions.

The major-minor aspect of the INDSCAL solution is clearly revealed as well as a dimension related by units of fifths to the pitch level of the chords. The interpretation of the vertical dimension as pitch level may seem inappropriate. That is, there is a pitch decrease from C to G and from A minor to E minor. If, however, the G triad is transposed up an octave it falls a fifth above C. That such a transposition operates at the level of perception was cleverly demonstrated by Shepard (1964).

There is evidence that the audio data are plagued with noise. First, M-D-SCAL solutions for the audio data had unacceptable stress values which could indicate noisy data. Second, the correlation values between subjects on the audio condition were not as high as in the written condition (see Table 2, Rows 1 and 2). Third, the fit to the INDSCAL solution for two dimensions for the audio data explained less of the variability in the data (see Table 1, Columns F and G). One factor accounting for the noise may be the way chords were played on a piano. Since the triads were played "live" for each subject, intensity and duration

could not be controlled. However, the subjects were asked not to use intensity or duration in making their judgments. The ideal situation would be one in which the sounds are carefully prepared on tape and made available to the subject to listen to as many times as necessary which would also eliminate any reluctance by the subject to ask to hear chords over again.

Possible Objections

M-D-SCAL offers interesting and convincing solutions for the "imagined" data but some of these solutions are not compatible with the INDSCAL model. The circular M-D-SCAL plot (see Fig. 3) cannot be formed by weighting the two orthogonal dimensions of the INDSCAL model. This circular solution has two possible interpretations. The first relies on the concept of relative major and minor. Moving in a clockwise direction the triads are relative minors or relative majors of the next chord, that is, D minor is the relative minor to F and F is the relative major to A minor. The jump between D and D minor represents the many missing triads which would complete the circle. By looking at Figure 1 a second and obvious decision process is observed: "two notes in common," that is, two chords sound alike if they have two notes in common. By raising or lowering the octave the circle is formed.

This leads us to a second possible objection. Subjects may not be imagining the sounds at all but using verbal descriptions of the triads. A possibility for meeting this objection would be to use less analysable stimuli, such as, the sounds of percussion or orchestral instruments.

Another possible objection is that the subjects, DS and JP, who show a strong relationship between the "heard" and "imagined" condition did so by naming the chords in the "heard" condition and then making the judgments in a fashion as to be consistent with their "imagined" judgments. This seems unlikely. First, the subjects were warned not to consider their "imagined" judgments. Secondly, except for TP, the INDSCAL subject space shows considerable agreement between the subjects in the use of the two underlying dimensions in the "heard" condition (see Fig. 5).

Conclusions

The purpose of this study was to assess the extent to which musical images of chords are veridical and the extent to which internal representations of chords parallel music theory. The following conclusions have been made.

1. The two dimensional INDSCAL solution provided a convincing account of the overall subjective dissimilarity between the chords in both the heard and imagined conditions. The first dimension was

related to the major-minor aspect and the second to the pitch level.

2. Two of the subjects appear to have veridical imaginations, that is, the imagined and auditory judgments appear to be generated from the same underlying structure.
3. For those subjects that do not have veridical imaginations, knowledge of their location in the INDSCAL subject space could be useful in learning what aspects of the triads should be emphasized in imagery training.

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