PERCEPTUAL STRUCTURE OF EVERYDAY SOUNDS: A MULTIDIMENSIONAL SCALING APPROACH

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ABSTRACT

The present study was designed to provide insight into the perceptual structure of everyday sounds. A large stimulus set of 74 sounds was used to gather sorting data, attribute ratings, and acoustic measurements for analysis using multidimensional scaling solutions (MDS). Correlations between and among the acoustic measurements and attribute ratings were as expected. The resulting MDS solution with regressed vectors for attribute ratings and acoustic measurements reveals a well-defined 3-dimensional perceptual structure for this stimulus set. Dimension 1 is defined by 5 perceptual attributes and 3 acoustic measures; Dimension 2 is explained by 1 perceptual attribute and 1 acoustic measure; and finally Dimension 3 is characterized by 3 perceptual attributes and 1 acoustic measurement. Information about perceptual structure can be used by researchers to increase basic knowledge about how people perceive the relationships among everyday sounds as well as by designers of virtual reality environments to assist in developing algorithms for realistic synthesized sounds.

1. INTRODUCTION

Research on the perception of everyday sounds has been limited. There have been studies focusing on the acoustic properties of ecological sounds [1][2][3], while others have taken into account perceptual, cognitive and acoustic factors [4][5][6]. The present study was designed to investigate the perceptual structure of a large set of everyday sounds using multidimensional scaling (MDS) to incorporate scaling data with attribute ratings and acoustic measurements.

This study consists of three parts. There is a sorting task for 74 everyday sounds used to obtain the data for the MDS analysis, an attribute rating task of the stimulus set to provide additional perceptual data, and a set of basic acoustic measurements of the 74 stimuli to provide information about what physical characteristics of the stimuli may be driving the perceptual structure. All three sets of data are used together to develop a “map” of the perceptual structure for the set of 74 everyday sounds examined. The analyses consist of simple correlations for the attribute ratings, the acoustic measurements, and intercorrelations between these two sets of variables together as well as an MDS analysis with the attribute ratings and the acoustic measurements regressed into the solution space.

2. PERCEPTION OF EVERYDAY SOUNDS

2.1. Sounds Sort

MDS analyses require data that are obtained by either paired comparisons or sorting tasks. The larger the number of stimuli under investigation, the more difficult is it to use paired comparisons as the data collection method, since the number of pairs necessary increases geometrically. Studies using visual and tactile stimuli routinely use sorting tasks [7] [8] [9]. Recently the validity of using sorting tasks for sounds has been tested and shown to be effective with two different sets of auditory stimuli [10]; thus, this method of data collection is used in the present study.

2.1.1. Participants

The participants in this portion of the study were 133 college students, who received extra credit for psychology courses for participating. After preliminary analysis, 17 participants were excluded from the data set due to missing data. Thus, the total number of participants included in the final sample was 116 (86 females and 30 males). All participants had normal vision and hearing and ranged from 19 to 22 years of age with a mean age of 19.03 years.

2.1.2. Apparatus

MacIntosh 7100/80 computers were used for stimulus recording and for stimulus presentation. The Canary Bioacoustics Workstation (1.1) software package was used to present the icons that represented the sounds and to play sounds to the participants during the sorting task. An Onkyo HX-PRO stereo cassette tape deck with a Yamaha RX-596 stereo receiver was used for stimulus recording onto cassette tapes and for the presentation of the entire set of stimuli to the participants at the beginning of the experiment. Finally, Sony MDR-CD850 stereo headphones were used for all sound presentations.

2.1.3. Stimuli

The stimuli consisted of 74 sounds made by objects that individuals in the United States would have exposure to on a regular basis (see Figure 1 for a list of the sounds). Forty-one of these sounds were taken from a study by Ballas [4] and the rest of the sounds were selected from a list generated by a group of 5 student research assistants and the researcher. Most of the sounds were recorded and digitized in our laboratory using the Canary Bioacoustics Workstation (1.1) software package with a MacIntosh 7100/80.power PC. The stimuli were digitized using a sampling size of 8 bits, a sampling frequency of 22.3 kHz, and a sampling rate of 22,254.5 Hz.

Additional sounds were taken from sound effects compact disks. The total set of sounds range in duration from 75.5 ms to 4714 ms with a mean duration of 1539.2 ms.

The sounds were also recorded in two different orders on cassette tapes with each sound played twice consecutively with 1.5 second pauses between individual sounds. These tapes were used for the initial exposure of participants to the sounds prior to the sorting task.

comb (thumbed)	waxpaper (crumpled)
record (scratched)	spray bottle (sprayed)
sandpaper(scraped)	plastic bag (crumpled)
cotton fabric (ripped)	saw (sawing wood)
paint brush (brushed)	balloon (inflating)
corduroy (rubbed)	wood file (scraped wood)
marker (moved on paper)	scotch tape (pulled roll)
pen (scribbling)	pencil sharpener (on)
duct tape (pulled from roll)	metal trash can (moved)
chalkboard (erased)	aerosol can (sprayed)
salt (sprinkled on paper)	fan (whirring)
eraser (moved on paper)	jar lid (opened)
spiral notebook(torn page)	paper (tearing)
nail file (moved on nail)	hair brush (thumbed)
cards (shuffled)	ratchet (twirling)
zipper (unzipped)	coins (shook)
toothbrush (thumbed)	electric drill (on & off)
Velcro (pulled apart)	vacuum (on & off)
metaltape measure (pulled)	aluminum foil (crumpled)
can opener (turned on)	hairdryer (on & off)
thermos bottle (open/shut)	water (poured)
chalkboard (written on)	scissors (open & shut)
rice krispies (with water)	bike pump (pumping)
scales (stepped on)	rice krispies (poured)
chain (clinked)	coat hangers (dropped)
nails (dropped)	sleigh bells (jingled)
keys (jingled)	video case (shut)
Tupperware (open & shut)	toaster (lever up & down)
combination lock (open)	stapler (stapling)
clock (ticking)	light switch (flipped)
soda can (opened)	mousetrap (snapped)
plates (clinked together)	3-ring binder (open/shut)
rubberband (snapped)	pans (clanked)
keylock (locked)	silverware (dropped)
purse snap (snapped)	jacket snap (snapped)
elastic (snapped)	book (shut)
basketball (bounced)	drinking glass (plinked)

Figure 1. List of 74 everyday sounds used in the study.

2.1.4. Procedure

Participants completed a three-part procedure during 1.5 hour sessions. Two participants completed the procedure at a time, and each was assigned to a computer. During the first part of the procedure, they filled out a short demographic questionnaire, and then they performed a practice sorting task with color cards. The purpose of this task was to make sure that the participants understood the concept of sorting stimuli. They were presented with a set of 40 cards with different hues. The task required them to sort the cards into groups of colors that they believed belonged together. They were required to have at least 2 cards to form a "group". The instructions emphasized that the participants should take their time and place the colors into groups according to how they believed they related to one another. They were also told that there was no right or wrong way to perform the color sort.

In the second part of the study, participants listened to all 74 sounds presented from a cassette through headphones. The experimenters told the participants that they should think about the types of characteristics of the sounds they wanted to use to sort them in the final task of the experiment. They were also informed that they should not try to identity the objects that made the sounds and that they should use the actual sound as the basis for thinking about the upcoming sorting task.

In the third and final part of the procedure, participants were taught how to play the sounds and sort them using a practice set of 3 stimuli. The icons in the Canary Bioacoustics Workstation were used to play the sounds and to represent them on the screen. Participants were assigned to one of two orders of the stimuli to control for possible order effects. The screen had all 74 stimuli in 4 columns on the left side of the screen (see Figure 2 below). Participants were instructed to begin at the bottom of the right most column. First, they opened the sound file, listened to the sound through headphones, and then moved the icon to a column on the screen. They proceeded to repeat this procedure for each additional sound, placing similar sounding stimuli into the same column. The experimenters told the participants that they needed to have at least 2 sounds to form a group and that they also needed a minimum of 6 groups. It was emphasized that the participants should focus on the similarity of the sounds and not take into account what objects might have made the sounds. They were also told that they should take their time to do a sort that best reflected how the stimuli belonged together. Participants were allowed to listen to all sounds as many times as they wished while they sorted the stimuli. They were also required to do a final check of their sort by listening to all the sounds in their groups and making any necessary changes to make sure the groups accurately reflected which sounds belonged together. Finally, scratch paper was provided so that the participants could make notes during the sorting task if they wished.

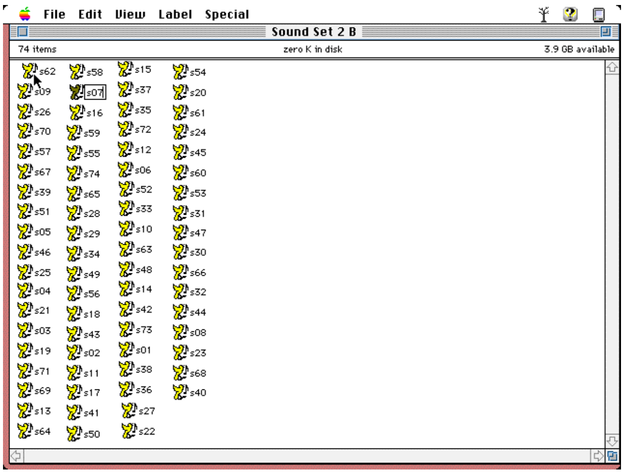

Figure 2. Example screen for auditory sorting task.

Once the sound sorting task was completed, participants filled out a follow-up survey that asked questions about the difficulty of the task, which stimuli were difficult to place in groups, and what attributes of the stimuli they used for the task.

2.2. Attribute Ratings

Attribute ratings were used to help determine the perceived characteristics of the stimuli that might be driving the resulting MDS solution obtained from the sorting data. Such stimuli are routinely used in this type of analysis to assist in defining the perceptual dimensions of the solution space [11][12].

2.2.1. Participants

Participants in this portion of the study were 75 college students who received course credit for participation, and all of them reported having normal hearing. They were assigned to one of three sets of attributes. There were 10 participants removed using an outlier analysis, which resulted in a total of 65 participants (42 females and 23 males) ranging in age from 18 to 23 years old with a mean age of 20.3.

2.2.2. Apparatus

The same equipment was used as in the sounds sorting task.

2.2.3. *Stimuli*

The 74 sounds were recorded in two random orders on cassette tapes. Each sound was presented twice consecutively, and there were 5 second pauses between the stimuli to provide time for the participants to rate the stimuli on the attributes. There were a total of 12 attributes rated for each stimulus (dull/sharp, relaxed/tense, round/angular, unpleasant/pleasant, slow/fast, cold/hot, weak/strong, low/high, soft/loud, uninteresting/interesting, rough/smooth, and compact/scattered). These attributes were chosen considering past research on similar types of sounds [4]. All ratings were performed using a 7-point scale with the low value assigned to the first attribute in each pair listed above.

2.2.4. Procedure

Participants completed the procedures in groups of 1 to 4 individuals. They were seated with their backs to one another, and each individual had his or her own set of headphones. At the beginning of the hour procedure, participants filled out basic demographic information including age and sex. They were then told that they would be listening to 74 sounds to familiarize them with the full set and range of the sounds and that they needed to rate them on the 4 attribute rating scales appearing on their data collection sheets. During the exposure to the complete set of sounds prior to the rating task, participants were told to think about the attributes on their sheets and consider how they should be applied to the auditory stimuli. Then they performed 3 practice trials with sounds not contained in the actual stimulus set before the data collection trials to make sure that the participants understood the task. Finally, for the actual attribute ratings, it was also emphasized that they should listen carefully to the sounds as they were played twice and give as accurate a rating as possible according to how they perceived the sound in relation to the attributes.

2.3. Acoustic Measurements

Like the attribute ratings, acoustic measurements of the sounds were also used to help define the dimensions of the MDS solution space. For these acoustic measurements, a MacIntosh 7100/80 computer with the Canary Bioacoustics Workstation was used. Measurements were taken for each of the 74 sounds and included measures from the spectrums and spectrograms. The measurements included were average intensity (the energy flux density divided by the duration of the sound); change in frequency (difference between the upper and lower frequency in the sound); change in time (duration of the sound in seconds); change in intensity (intensity in Hz from one end of the sound to the other); amplitude ceiling, (highest amplitude level in the sound) dynamic range (difference between amplitude floor and ceiling), peak intensity (maximum intensity/Hz), and peak frequency (frequency at which the highest amplitude occurs). It should be noted that these specific measurements are basic and do not reflect the range of sophisticated measures that can be performed with other types of sound analysis equipment.

3. RESULTS & CONCLUSIONS

3.1. Outlier Analysis for Attribute Ratings

An outlier analysis was performed using the EXPLORE procedure in SPSS for the attribute ratings. Extreme outliers were removed from the data set at the stimulus level. Any participants who had more than 5 extreme outliers had all of their data removed from the data set. There were 10 participants who were excluded using this criterion.

3.2. Correlations Among Attribute Ratings

	DUSH	RETE	ROAN	PLEA	SLFA	COHO	WEST	LOHI	SOLO	INTE	ROSM	COSC
DUSH	----											
RETE	.82*	----										
ROAN	. 72*	.75*	----									
PLEA	-.60*	-.84*	-.66*	----								
SLFA	. 05	-.05	-.03	.12	----							
COHO	.06	.06	.03	.03	.43*	----						
WEST	.09	.02	.03	.06	.61*	.56*	----					
LOHI	-.01	-.10	-.15	.12	.56*	-.11	.40*	----				
SOLO	. 73*	.66*	.39*	-.50*	-.03	.09	.01	-.04	----			
INTE	.20	.13	-.08	-.07	.07	.03	.03	.25	.40*	----		
ROSM	-.38*	-.53*	-.51*	.56*	.19	-.12	-.06	.15	-.34*	-.21	----	
COSC	-.01	-.03	-.03	.03	.17	.17	.14	.17	.11	.63*	-.42*	----

Figure 3. Correlation matrix for attribute ratings.

The correlations among the attribute ratings are shown in the correlation matrix (Figure 3). The abbreviations used in the matrix are as follows: DUSH = dull/sharp; RETE = relaxed/tense; ROAN = round/angular; PLEA = unpleasant/pleasant; SLFA = slow/fast; COHO = cold/hot; WEST = weak/strong; LOHI = low/high; SOLO = soft/loud; INTE = uninteresting/interesting; ROSM = rough/smooth; and COSC = compact/scattered.

The correlations among the attribute ratings reveal that dull/sharp, round/angular, and relaxed/tense are positively correlated with one another and also show the same pattern of correlations with the rest of the attribute ratings such that they are positively correlated with soft/loud and negatively correlated with unpleasant/pleasant and rough/smooth. Rough/smooth is positively correlated with unpleasant/pleasant, and both of these attributes are negatively correlated with soft/loud. This set of correlations makes sense since stimuli that are dull should also be round, relaxed and soft as well as pleasant and smooth.

In addition, rough/smooth is negatively related to compact/scattered, which was expected since stimuli that are compact should be smooth. Slow/fast and weak/strong are positively correlated with one another as well as with low/high, and cold/hot. Once again, these relationships are logical since objects that are fast and strong tend to be hot and "high". Finally, only two attributes are correlated with uninteresting/interesting such that compact/scattered and soft/loud are positively related and rough/smooth is negatively related. Thus, it appears that sounds that have more "texture" and loud are more interesting to the listener.

3.3. Correlations Among Acoustic Measures

	AMPL	AVIN	CHFR	CHIN
AMPL	----			
AVIN	.96*	----		
CHFR	.49*	.49*	----	
CHIN	-.01	-.039	-.03	----
CHTM	-.20	-.22	-.20	-.09
DYNA	.15	.14	.06	-.08
PKFR	.77*	.77*	. 33*	.10
PKIN	.27	.32*	.05	-.14

	CHTM	DYNA	PKFR	PRIN
AMPL				
AVIN				
CHFR				
CHIN				
CHTM	----			
DYNA	-.08	----		
PKFR	-.45*	.02	----	
PRIN	.01	-.04	.06	----

Figure 4. Correlation matrix for acoustic measures.

The correlations among the acoustic measures are shown in the correlation matrix (Figure 4). The abbreviations used in the matrix are as follows: AMPL = amplitude ceiling; AVIN = average intensity; CHFR = change in frequency; CHIN = change in intensity; CHTM = change in time; DYNA = dynamic range; PKFR = peak frequency; and PKIN = peak intensity. The correlations among the acoustic measures show that average intensity and amplitude ceiling are positively related to one another and also both are positively correlated with change in frequency and peak frequency. In addition, peak frequency is also negatively correlated with change in time, and average intensity is positively related to peak intensity. Taking into account what each of these variables measure, the relationships among them are reasonable and would be expected to occur.

3.4. Correlations Among Acoustic Measures and Attribute Ratings

The intercorrelations among the acoustic measurements and the attribute ratings will not be presented in a correlation matrix due to space limitations. However, there were signification correlations between these two sets of variables and the following discussion will address these in narrative form.

Dull/sharp was significantly correlated with 6 of the 8 acoustic variables, such that there were positive correlations with amplitude ceiling, average intensity, change in frequency, change in intensity, and peak frequency as well as a negative correlation with change in time. Soft/loud was positively correlated with amplitude ceiling, average intensity, change in intensity, and peak frequency. Round/angular was negatively related to change in time and positively related to peak frequency and had a marginally significant negative linear relationship with peak intensity. Relaxed/tense was positively correlated with amplitude ceiling and peak frequency, and had a marginally significant positive correlation with average intensity. Weak/strong had a positive linear association with change in intensity. In addition, cold/hot was positively correlated with change in intensity; compact/scattered and uninteresting/interesting were positively related with change in time and both had a marginally significant positive relation with dynamic range; and unpleasant/pleasant was negatively related with peak frequency. Finally, rough/smooth and low/high had no significant linear relationships with any of the acoustic measurements.

This set of intercorrelations among the acoustic measurements and the attribute ratings are logical in terms of what each of them measures, and these relationships should be reflected in the regressed attributes in the MDS solution space.

3.5. Multidimensional Scaling Analysis

The MDS analysis produced using ALSCAL revealed that either a 3-D or 4-D solution space would be acceptable using scree plots of the measures of fit (stress values = .429, .238, .164, .118, .092, and .071 and R^2 = .484, .711, .799, .867, .902, and .932 for solutions with Dimensions 1 through 6 respectively) [11] (see Figures 5 & 6).

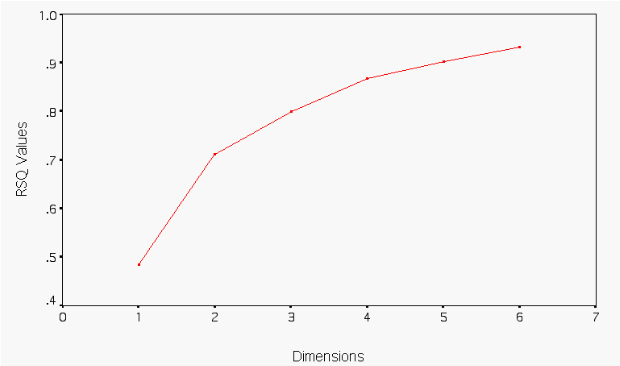

Figure 5. Scree plot for the R^2 values for Dimensions 1 through 6 for the MDS solution for the sound sort.

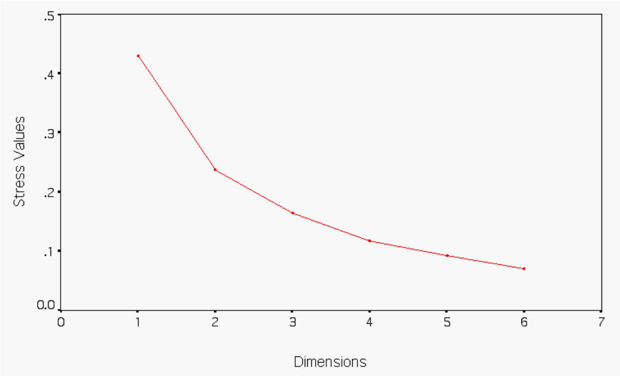

Figure 6. Scree plot for the stress values for Dimensions 1 through 6 for the MDS solution for the sound sort.

To facilitate the interpretation of the solution, the attribute ratings and the acoustic measurements were regressed onto the 3- and 4-dimensional solutions. This was performed by using a series of multiple regression analyses with attribute ratings and acoustic measurements as criterion variables and the dimensional coordinates as the predictor variables [9] [12][13][14]. These analyses showed that the 4th dimension did not add explanatory power to the analysis; thus, the 3-D solution was chosen for as the most representative MDS solution for the stimuli. Following the recommendations of Schiffman et al. [12], the positions of the significant attribute ratings and the acoustic measures were placed as vectors into the solution space using the standardized regression coefficients from the regression analyses. The length of each vector corresponds to the R^2 values which demonstrate the variance of the ratings and measurements captured by the MDS solution; thus, shorter vectors show a poorer fit while longer vectors show a better fit to the solution space [9] (see Figures 7, 8, 9 & 10).

It is important to note that the MDS solution space is in 3-dimensions; thus, the best description of the stimulus space and the related variables would be a 3- rather than 2-dimensional approach. However, it is not possible to produce a 3-D drawing of such a solution space with the regressed vectors that is visually effective; therefore, the following description will focus on 2-dimensional displays of the 3 dimensions. This is a less complete and less robust description of the solution space than could be presented with a 3-D approach; however, it seems to be the best alternative given the constraints of 2-dimensional representations on paper. The graphs were set-up using Dimensions 1 and 2 and Dimensions 1 and 3 since they display the attribute ratings and acoustic measurements and their relations to the perceptual space most clearly.

Attribute	R^2 value	p value
DUSH	.103	.04
RETE	.163	.005
ROAN	.055	.26
PLEA	.18	.002
SLFA	.097	.05
COHO	.013	.80
WEST	.039	.42
LOHO	.065	.18
SOLO	.153	.008
INTE	.241	.001
ROSM	.236	.001
.COSC	.357	.001

Figure 7. R2 values from regressions of the attribute ratings into the 3-D solution space.

Acoustic Msr	R^2 value	p value
AMPL	.211	.001
AVIN	.197	.001
CHFR	.168	.005
CHIN	.034	.48
CHTM	.371	.001
DYNA	.018	.73
PKFR	.307	.001
PKIN	.027	.58

Figure 8. R2 values from regressions of the acoustic measurements into the 3-D solutions space.

Inspection of Figures 9 and 10, which provide a map of the perceptual space with the significantly related attribute ratings and acoustic variables added as vectors, show the following relationships. Dimension 1 is defined by the perceptual variables of compact/scattered, dull/sharp, slow/fast, uninteresting/interesting, and rough/smooth while the acoustic measures that characterize the first dimension are amplitude ceiling, average intensity, and change in frequency. For Dimension 2, low/high and change in time provide explanatory power. Finally, relaxed/tense, unpleasant/pleasant, and soft/loud characterize Dimension 3 along with amplitude ceiling and peak frequency.

Further inspection of the Figures 9 & 10 using the attribute ratings reveals that that Dimension 1 has the attributes slow, scattered, sharp and rough on the right side of the display. The stimuli along this edge of Dimension 1 fit these descriptors well; for example, silverware (dropped), drinking glass (plinked), and basketball (bounced) are the most extreme points on this end of Dimension 1. The left edge of Dimension 1 has the opposite end of the above mentioned attributes (fast, compact, dull, and smooth), and the stimuli in the extreme end of the dimension match these attributes well (salt [sprinkled]; corduroy [rubbed]; chalkboard [erased] and a comb [thumbed]).

Dimension 2 appears to be best characterized by low on the bottom of the display, with stimuli at this end of the attribute consisting of paper (tearing), scissors (opening and closing), and bike pump (pumping). The top edge of Dimension 2 is defined by the attribute high with stimuli such as fan (whirring), water (pouring), and rice krispies (pouring water on).

Finally, Dimension 3 appears to be defined by relaxed, soft and pleasant on the top edge of the map, which has stimuli such as jar lid (opened), thermos (open and shut), and scales (stepped on). The bottom edge of Dimension 3 reflects the other end of the continuum for the aforementioned variables with loud, tense, and unpleasant. It is interesting to note that the stimuli at this extreme edge are all electrical machinery (hairdryer [on & off]; electric drill [on & off]; and vacuum [on & off]).

The placement of most of the acoustic vectors within the 3-D solution space is not as “clean” as the placement of the attribute ratings. Most of these variables have significant standardized beta weights with more than one dimension, unlike the attribute ratings. This results in the inability to easily relate each of them to one single dimension since they “cut through” the 3-D space. This should be kept in mind for the following brief discussion of these vectors.

Peak frequency defines Dimension 3 with the lower edge related to high frequencies and the upper edge related to low frequencies. Change in time most closely lines up with Dimension 2 with stimuli at the lower edge of the figure for shorter times. Finally amplitude ceiling, average intensity, and change in frequency are related to both Dimensions 1 and 3.

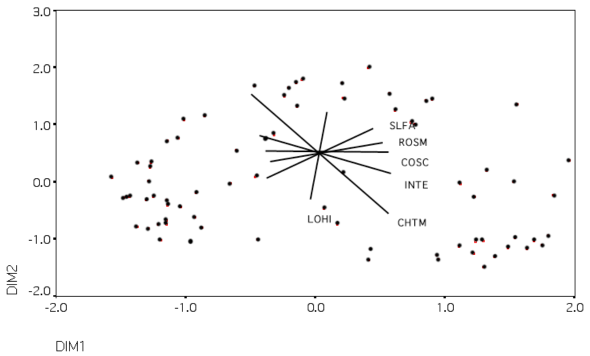

Figure 9. Dimensions 1 & 2 from the 3-D MDS solution with regressed attribute ratings and acoustic measures.

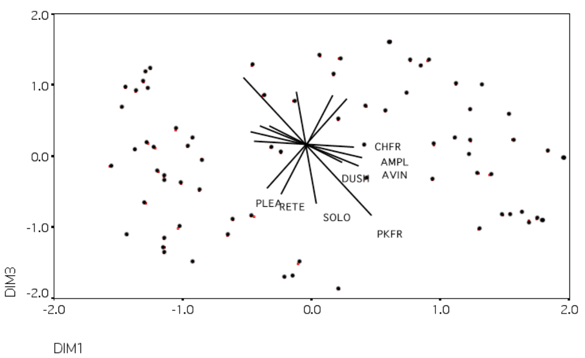

Figure 10. Dimensions 1 & 3 from the 3-D MDS solution with regressed attribute ratings and acoustics measures.

4. GENERAL CONCLUSION

These results suggest that these specific attributes and acoustic variables define the perceptual space for these stimuli. Future work should include other sets of everyday sounds to see if the structure remains the same. In addition, other perceptual attributes, and a wider variety of more complex acoustic measurements should be explored to determine the best variables to help explain such perceptual structures. Results from such studies could be used effectively not only to understand the basic perceptual structure people have for such stimuli, but they could also be used to help determine the important acoustic variables necessary to create algorithms that produce convincing synthesized sounds.

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