Understanding the Perception of Granular Processing

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I. Introduction

Granular processing of sampled audio signals (Roads 1985; Traux 1987) is a technique that has experienced increased interest in recent years. This processing technique has origins in the work of Dennis Gabor and his concept of the *acoustical quanta* (Gabor 1947), which was developed in response to perceptual research findings. He asserted that, "it is our most elementary experience that sound has a time pattern as well as a frequency pattern (Gabor 1947, p. 591)." Although several software applications are now widely available for realizing granular processing effects (Roads and Alexander 1997; Behles, Starke and Roebel 1998; van der Schoot 1999; Rolfe and Keller 2000), these programs have done little to clarify the perceptual connection between interface controls and audio output, a problem that has persisted since the first computer implementation was reported twenty-five years ago (Roads 1978). A better understanding of how the audio output is perceived is a necessary precursor to the development of a simplified interface that would require the computer "to interpret how to approximate a desired result" (Roads 2001a, p. 27).

In order to further this goal of understanding the perception of granular processing better, the author has conducted a series of three experiments based on models found within studies of musical timbre (Grey 1977; Wessel 1979; Kendall and Carterette 1991; Iverson and Krumhansl 1993). These studies have employed a method of exploring the topic using a similarity-scaling task. Subjects would listen to a series of pairs of sounds, rating the similarity of each pair member to the other while moving through all possible couplings of the stimuli. These similarity ratings were then averaged together and used as the basis for formulating a multi-dimensional scaling solution (Shepard 1962a, 1962b; Kruskal 1964a, 1964b). MDS uses these similarity ratings to produce a graphic representation of the relationships that exist within that data. Stimuli that are viewed as similar will be placed in close proximity to one another, while those viewed as dissimilar will be have a greater distances between them. The differences are represented in a single graphic plot of points representing the stimuli used. This seemed like an appropriate method to employ in our study, however we must emphasize that we are not attempting to draw connections between the results of our study and those found in timbre research. Our comparison is simply with their experimental methods.

II. Scope

Because granular processing is a technique that has many control parameters that often have an element of randomization to them and are allowed to vary over time, many self-imposed limitations will be necessary when generating stimuli for subjects in these initial experiments. All granular techniques have the common characteristic of using single grains in combination with each other to form larger, more complex sounds that can vary in their density of grains per second. Studying the perception of complex granular sounds produced with high densities will certainly be a long-term goal of this research. However, without prior limited studies to build upon, it would most likely prove too difficult to develop practical conclusions from an initial study using such complex sounds. In this regard, the fact that these more complex sounds are built from simple particles provides an advantage. It is possible to first create and study simple examples with static parameter settings, taking necessary small steps to lay a foundation for further research involving more dense and complicated combinations of grains.

In granular sampling, the grains consist of short segments sampled from the sound source being processed (Graph 0-1). Because the sample segment may not have smooth beginning and ending points, an amplitude envelope is applied to these segments (Graph 0-2). In essence, this envelope applies a fade in at the beginning and a fade out at the end of the grain (Graph 0-3). This prevents any clicks from occurring due to sample discontinuity. The most common window shape or windowing function used is based on the Gaussian normal distribution curve, which was originally proposed for windowing by Gabor (Gabor 1947). This is the same basic shape will be used to generate the stimuli for this study.

The grain length is used to describe the duration of a grain from its start to finish (Graph 0-4). Most granular techniques work with sounds that are on the order of 10 to 40 milliseconds in length. The reasoning behind this lower limit can partly be traced back to Gabor's 1947 paper, which cited 10 milliseconds as the "minimum duration…with ascertainable frequency (592)." Further studies related to this threshold list a range of minimum durations that are dependent on differences in frequency. Later studies conducted separately by Meyer-Eppler and Olson place the absolute minimum duration at 13 milliseconds, with limits as high as 45 milliseconds for lower frequencies (cited in Butler 1992, p. 89). The stimuli used in this study will have grain lengths encompassing this range. Although static length settings will be used in stimuli for the first and third experiment, the second experiment will explore the effects on perception when length is allowed to vary stochastically.

The grain period is the amount of time between consecutive beginnings of two grains (Graph 0-5), and is analogous to an inter-onset interval. The onsets of grains in time are typically randomized, thereby avoiding any regular period among a series of grains. This sort of stochastic organization has been described as asynchronous (Roads 1991) and is part of what gives granular sounds their distinct complexity. Grains are sometimes also allowed to overlap one another, producing thicker textures as they combine to increase the overall signal strength. For the first two experiments in this study however, stimuli will be generated with non-overlapping grains at a consistent granular period in order to make the interaction between period and length more clear. This form of grain organization is closer to a method that is referred to as quasi-synchronous (Roads 1991; Truax 1994). The last experiment within this study will use stimuli that are organized more like the asynchronous model with stochastic variations in period, but this complex example will only provide useful observations once the subjects’ ability to perceive differences in the simpler, quasi-synchronous granular examples has been established.

In addition to common grain lengths between different grain periods, consideration will also be given to the ratio of the grain length to the grain period. Such ratios are the focus of a related synthesis technique known as pulsar synthesis (Roads 2001a, 2001b). By including some consideration for these ratios, this study intends to perhaps determine which method of organization is most perceptually relevant to subjects. The perception of differences in grain length, period and length-to-period ratio will be the primary inquiry of the three experiments within this study with the focus on determining what relationships are perceived by the listeners in these parameter differences.

Granular sampling has several parameters that control how samples are drawn from the sound file being sampled. The rate of sample playback within a grain can affect the perception of pitch upon output. Because of this relationship, the parameter that affects the *sampling increment* is most often referred to in terms of pitch or harmonizing. It is this parameter that allows control over changes in pitch independent from time manipulations, either at harmonic intervals by using whole number increments or non-harmonic intervals when fractional increments have been implemented (Truax 1994). The experiments proposed in this study will use stimuli devoid of such sampling increment or pitch variations and a constant sampling increment of 1.0 will be used.

In addition, the position within the source sound file from which segments are taken must be specified. Known as the *sample offset*, this parameter is a statement of the amount of time after the beginning of a sound file to begin sampling for the grains being produced (Truax 1987). This sample offset, like other parameter settings, can also be expressed as a range within which random deviation can occur. The stimuli for this study will use a fixed sample offset, which should make the consecutive grains sound identical to the listener.

The settings for each stimuli generated will remain static for the duration of the sound. This study will limit its focus to the perceptual differences reported by subjects resulting from variations in the areas of grain length and period. With this aim in mind, settings will be changed between stimuli to create differences in only these parameters. The stimuli within the first experiment will contain static settings for their lengths and periods, with consideration given to the length-to-period ratio as well. The second experiment will contain stimuli with static periods between grain onsets and various degrees of randomization placed upon their lengths. For the final experiment the opposite will be true, using stimuli with static length settings and various degrees of randomization placed upon the granular period parameter. The end result of all these restrictions upon the processing parameters admittedly makes the stimuli somewhat basic examples of granular processing, but it is necessary to take small steps in this new endeavor. Once the initial findings of this study have been reported, it is the author's hope that future research can be conducted that expands the focus to the perceptual differences in other parameter settings for granular sampling.

The sound source used for the processing has a major effect on the output. Audio output from granular processing retains some of the acoustic qualities present in the original recording being used. It will be necessary to produce stimuli that result from different recordings with consistent parameters settings so that the perception of the sound source can be compared with the perception of the processing alone. The original intent in the experiment design was to use three source timbres for each experiment to produce stimuli with the given processing settings. For each of the specific processor settings, three different timbres would be sent through the granular processing at those settings resulting in three different versions of the processed stimuli. Three sources were recorded by the author at the Summit Studio at Northwestern University. A hand bell used for choir ringing, a flute and a female vocalist were all recorded using a Shure SM81 microphone and a Joe Meek pre-amp without compression. The signal was recorded with a ProTools 5.1.1 system running on an Apple Macintosh dual-processor desktop computer using a Digidesign 888 audio interface. All recordings were made at a sampling rate of 44.1 kHz and bit depth of 16.

The Schulmerick hand bell, pitched at A5, was recorded first and then used as a reference for tuning of the flute and vocalist before they were recorded. Equalization settings were kept at a minimum and remained the same for all three recordings. The flute was played with a straight, dark tone. The female vocalist was instructed to sing her pitch on a “long e” vowel sound. A single note from each of the resulting recordings was selected and, after being normalized, bounced into a sound file by itself. These resulting files were kept at the same sampling rate and bit depth as the original recordings.

After recording the timbre sources, the decision was made to reduce the number of source timbres used in order to maximize the number of parameter settings we were able to investigate in each experiment. We revised the stimuli production plans to include two timbres and nine processing settings per experiment.

A secondary benefit of this decision was the prevention of any possible interference between the subjects' perception of timbre and the granular processing parameters. Since timbre is itself regarded as a multidimensional percept, three timbre sources could have caused the perceived differences to be manifest within several dimensions of the multidimensional scaling solution. With only two timbres, the task for the subjects is simply a matter of distinuishing between them and should manifest itself as a dichotomy.

Since three sources had already been recorded, a method was devised for selecting the two most different timbres from among the three. Using a single processor setting with a grain period of 93 milliseconds and a grain length of 43 milliseconds, all three source timbres were processed to produce stimuli similar to those that would be used in the three main experiments. Ten volunteer subjects were informally asked to listen to all six of the possible pairs from the triangular matrix created by these three stimuli and rate the similarity of each pair. The procedure was similar to that of the main experiments with the subjects listening over headphones instead of a loudspeaker. Responses were recorded by a computer via an onscreen slider that hid a 0 to 500 scale. The subjects' responses for each pair were averaged together to produce a triangular matrix of the statistical means (see Table 0-6).

We decided that the most dissimilar pair would be the most desirable basis for stimuli creationsince our goal in including different timbres was simply to determine if any granular processing settings would interfere with the distinctions between timbres. If any confusion was present in the MDS solutions, it was likely to be most clear if the sources were very dissimilar. It is clear from the chart that the pairing of the female vocal and bell timbre sources was rated the most dissimilar by these subjects. This is the pairing that was used to produce all of the stimuli for the three experiments described in this study.

III. Research Questions & Operational Definitions

A. Primary Research Questions

1) What are the perceptual characteristics represented in the multidimensional scaling solution based participants' responses to the presented stimuli pairs?

Null hypothesis: The analysis of the multidimensional scaling solution will provide no clear distinctions between granular processing stimuli.

2) How do these characteristics relate to the explicit differences in parameter settings applied to the production of various stimuli?

Null hypothesis: No clear relationship will be observed between the parameter settings and the multidimensional scaling solution.

3) Do the acoustical characteristics of the sound source affect the placement of the resulting stimuli within the multidimensional scaling solution relative to other stimuli that result from different sources processed using the same algorithm settings?

Null hypothesis: The will be no difference in the placement of varying sound sources processed via identical granular settings within the multidimensional scaling solution.

B. Secondary Research Questions

1) Does a participant's experience with listening to electro-acoustic music affect his or her responses to the granular processing examples?

Null hypothesis: There will be no significant difference between the responses given by listeners of electro-acoustic music and the other participants.

2) Does a participant's experience in composing electro-acoustic music affect his or her responses to the granular processing examples?

Null hypothesis: There will be no significant difference between the responses given by composers of electro-acoustic music and the other participants.

C. Operational definitions

Electro-acoustic listener – a participant that reports listening to an average of five or more electro-acoustic works per month.

Electro-acoustic composer – a participant that reports having composed five or more electro-acoustic works in his or her lifetime.

IV. Experiment One

The first experiment in this series of three was designed to test for the perception of basic manipulations in the granular processing. Using two source samples, 18 stimuli were produced using nine specific pairs of grain length and granular period. No randomization was allowed for these two parameters, resulting in stimuli that had a regular pulse to them. In developing the series of values used (see Table 1-1), consideration was also given to the resulting ratio relating the length to the period.

A similarity-scaling task based on those used in previous studies involving the perception of musical timbre (Grey 1977; Wessel 1979; Kendall and Carterette 1991; Iverson and Krumhansl 1993) was employed. These similarity ratings will be used to develop multi-dimensional scaling solutions (Shepard 1962a, 1962b; Kruskal 1964a, 1964b) in the hopes that significant correlations may be found between their coordinates and the granular processing parameters used.

In the analysis, between-subject variables related to the subjects' experience with listening to and composing electroacoustic music were tested for any possible effect on their similarity ratings. These groupings were examined because listeners and composers of this musical genre may possibly be familiar with sounds produced with this processing technique, as well as being more familiar with other forms of unusual sonic manipulations.

A. Subjects

Potential subjects were drawn from the student population in the Audio Arts and Acoustics department at Columbia College Chicago. Each was asked to provide an assessment of the total number of years of training in the areas of music and audio or recording technologies by answering the two following questions:

1) "How many years of training or study do you have in music?"
2) "How many years of training or study do you have in audio and/or recording technologies?"

They were asked to round their answers up to the nearest whole number. Only those whose two answers resulted in a total of at least four years were asked to participate in the full experiment.

A total of twenty subjects participated in the full study. All were volunteers and were not compensated for their time with money or course credit.

B. Apparatus

Audio playback was presented over a single Tannoy System 10 DMT II speaker with concentric drivers placed directly in front of the subject. It was powered by the left channel of a Crown SA 30-30 amplifier. A Dell Latitude laptop computer running Windows 2000 handled stimuli playback, with the built-in sound card being connected to the amplifier. The same computer was also be used by the subjects to enter their responses after each presentation for later analysis. An optical mouse was connected to the computer for the subjects to use when making their responses. Stimuli playback and recording of subject responses was managed by a software application known as MEDS (Music Experiment Development System) developed by Roger Kendall of UCLA.

The room used was one that is typically used for recording as part of the facilities at Columbia's Audio Technology Center. Subjects were asked to sit facing the single speaker approximately 50 inches in front of them, with the center of the speaker cone 55.5 inches from the ground. The chair was raised so that subjects' heads were approximately level with the speaker. The computer was placed to the right of the seating position on top of a cart that was 34.5 inches high so that nothing was between the subject and speaker.

C. Stimulus materials

A total of eighteen stimuli were produced, resulting from two different recordings each being processed by the same set of nine parameter settings. The source recordings were of two different timbres, a bell and a female vocalist, sounding on the same pitch. In addition, a sample of pink noise was processed using the same nine parameter settings to produce the stimuli used in the practice segment of the experiment.

These sound files were processed using an audio synthesis patch created by the author using Cycling74's Max/MSP version 4.0.9 running on a Apple iBook. Both the source recordings and resulting stimuli were of CD-quality digital audio (44.1 kHz, 16 bit depth) in the AIFF format. Each stimulus was 700 ms long with an amplitude envelope that included a 100 ms linear fade-in and 100 ms linear fade-out. The length of these fades was chosen because it was longer than all the granular periods being used and would therefore have some effect on at least two complete periods of all of the stimuli. The resulting sound files were normalized using SoundHack 0.891 and converted from AIFF to WAVE format with SoundApp 2.6.1, so that they could be used within MEDS.

Grains were sampled from an offset of 200 ms from the beginning of each source sound file without any randomization of this position. A pitch multiplier of 1.0 was used without any randomization of this setting, resulting in a consistent sampling increment and therefore no apparent pitch change in the source sound. A Gaussian window was used as an amplitude function for all of the grains sampled. Specific pairings of grain length and period were the only parameters varied in the creation of these stimuli (see Table 1-1). No randomization was applied to either of these parameters.

D. Procedure

After reading through and signing a consent form that provided a basic explanation of the motivation behind the experiment and the procedure that was to be used, subjects were guided to the room used for the experiment. Subjects were given some basic verbal instructions in order to orient them to the space including where they could find the volume control. They were also told to make sure they faced the speaker when listening, since the computer was located to their right. After these brief instructions and answering any questions the subject had, the researcher would then leave the room for the duration of the experiment.

As the experiment software began running, subjects read the following text from the computer screen before:

"This experiment will require you to make judgments about the similarity of pairs of sounds and should last no more than 40 minutes. At this point you should have already filled out the necessary consent forms for participating in this study. As a reminder, if you decide at any time that you would like to halt your participation in this study, we will stop immediately and any data you have provided up to that point will be discarded. Furthermore, if you should have any questions at a future date about your participation in this study, you may use the provided contact information to seek answers. Do you understand? If so, click OK to continue. If not, please ask the researcher for clarification before proceeding."

Next the subjects saw a prompt reading, "Before the experiment begins, you must first answer a few questions about your prior experiences with music and/or audio technologies. Click OK to continue."

Subjects were first asked to enter their responses to the questions already posed during the pre-screening process via on-screen prompts. They were displayed as follows:

1) "How many years of training or study do you have in music?"

2) "How many years of training or study do you have in audio and/or recording technologies?"

Before the third and four questions the following prompt was displayed: "The next two questions relate to the following definition of electro-acoustic music:

> A type of music in which sounds are created and/or manipulated using computers and/or electronic musical devices. This designation IS NOT restricted to musical works of a certain aesthetic or style. It is based solely on the methods of sound production. Composed sounds within such a piece must be reproduced over loudspeakers or headphones in order to be heard. If such sounds are paired with traditional acoustic instruments, the piece is still considered to be electro-acoustic.

If you understand the above definition, click OK. If not, please ask for clarification."

After confirming that they understood this definition, they were presented with the following two questions and entered their answers via on-screen prompts:

1) "On average, how many electro-acoustic works do you listen to per month (please round up to the nearest whole number)?"
2) "How many electro-acoustic pieces have you composed in your lifetime (please estimate if necessary)?"

Based on their responses to these questions, participants were later classified as listeners and composers for the purposes of analysis according to operational definitions set ahead of time by the investigator (see section III above).

After answering these questions, participants were presented with the following text:

"You are about to hear pairs of sounds. For each pair that is played, consider the question, 'How much do you feel the first sound needs to be changed in order to make it the same as the second sound?' Click OK to proceed with the listening."

Responses were made by controlling an on-screen scrollbar with the computer's mouse and positioning it between two ends labeled "none" and "a lot". The slider was devoid of any markings indicating the scale used, hiding a resolution of 500 possible locations that could be given as responses. In addition, the question was kept in the upper left corner of the screen for the duration of the experiment so that subjects could refer back to it as necessary.

Participants were allowed to repeat the playback of a given pair as often as necessary before entering their response and take as much time as needed to make a judgment. The next pair was only played after the participant issued a response for the current pair.

Before listening to the complete set of stimulus pairs created using the two timbre sources, all 45 possible unique pairings were presented from the group of nine practice stimuli. These stimuli were produced using pink noise as the sound source and the aforementioned nine parameter settings. They were meant to provide the participants with a clear demonstration of the range of differences for which they should be listening. Participants rated them exactly as they would the actual pairings. This practice session was also used to set the playback volume at a level that is comfortable for each participant.

Subjects were prompted at the conclusion of the practice session by an on-screen message informing them that the actual experiment was beginning. Participants were then presented with all 171 possible unique pairs of 18 stimuli generated for this study in a random order and were be asked to respond as described above. These responses were recorded and used to generate the multi-dimensional scaling solution used for the final analysis.

The total time required of each participant to complete the procedure averaged approximately 45 minutes.

E. Results

The subjects were characterized according to the operational definitions as listeners and/or composers of electroacoustic music using their responses to the pre-experiment survey questions to test for any significant effects these distinctions may have upon their similarity ratings. These operational definitions divided the subject into very uneven groups and we therefore decided to also look for any significant effects the upper and lower halves of responses had as between-subject variables. For this division into halves it was necessary to develop some rules as to how to divide the group. We determined the first option should be to find a response that divides the groups evenly. If this was not possible and the groups must be uneven, the response value should above all divide the subjects as close to even as possible. If there were two responses that would divide the group unevenly in the same manner, there should be more in the "no" classification than "yes". For example, if a group could be divided as either 8 non-listeners and 12 listeners or as 12 non-listeners and 8 listeners, we would select the second option. Lastly, if these rules lead us to the same division that was created by the operational definitions, we would find the next closest grouping, applying the rules again.

Using these rules, subjects who responded with 20 or more to the first question were classified as being in the upper half of the listener respondents. Subjects who responded with 4 or more to the second question were classified as being in the upper half of the composer respondents. These resulted in much more even groupings than the original operational definitions (see Table 1-4a) and this method will therefore be repeated in the analysis of experiments two and three. In an analysis for significance using the general linear model to test the multivariate responses according to both of the operational definitions and population halves and the intersection of each, no significant effect was found for any of these categories ($df = 6$, $p>0.05$; see Table 1-4b). This means the subjects' experience with electroacoustic music appeared to have no effect upon their similarity ratings in this experiment and we can therefore analyze the MDS solution as representing the entire group of subjects and not separate sub-populations.

The subjects' responses were averaged together to create a single triangular matrix that was used to compute a two- and three-dimensional solution via multidimensional scaling. The ALSCAL algorithm under SPSS version 10.5 on a Windows-based computer was used to derive the solutions used for analysis.

The stress according to Kruskal's stress formula 1 for the two-dimensional solution was fairly low (*stress = 0.13587*) after only three iterations. The proportion of variation accounted for by this solution was relatively high (*RSQ = 0.90542*). This means that just over 90.5% of the variance observed in the resulting matrix was accounted for in the two-dimensional graphing solution output by the software (see Graph 1-2). The stress for the three-dimensional solution was lower (*stress = 0.08832*) and again required only three iterations of the algorithm. The amount variation accounted for by the added dimension also improved (*RSQ = 0.94444*). The improvement of 3.9% by adding the extra dimension means that this solution accounts for an even larger amount of the variation (see Graph 1-3).

The first thing that we noticed when looking over the two-dimensional MDS solution was the apparent division according to timbre. It is clear that dimension one is representative of the source timbre used in the processing, with those stimuli derived from the bell sample having negative values and those derived from the vocal sample having positive values. Looking at the raw coordinates from the three-dimensional solution (see Table 1-5b), this trend appears to be present in that graph as well. We were able to conclude from this that there was no apparent confusion between source timbres due to the processing that was taking place. However, we did note that the distance between stimuli of differing timbres appears to decrease as the length decreases. This could be due to the shorter grain lengths approaching the edge of timbre perception.

We will save any further discussion of the relationship between the MDS solution and processing parameters for the final analysis of all three experiment results.

V. Experiment Two

For the second of these three experiments, the processing used to produce stimuli focused on manipulations of the grain length and the amount of randomization applied to this parameter. A single granular period from among those used in experiment one was chosen and applied along with three of the grain lengths used. These three length values were combined with a group of randomization amounts to arrive at the series of nine parameter settings that were used (see Table 2-1) to process each of the two source timbres and produce the 18 stimuli used in this experiment.

Using the methods discussed in experiment one, experience with electroacoustic music was again examined for possible effects upon the similarity ratings provided. MDS solutions were produced and used to examine possible significance between the organization exhibited in subjects’ responses and the processing parameters used to develop the stimuli.

A. Subjects

Potential subjects were drawn from the student population in the School of Music at Northwestern University and asked to provide an assessment of their music and audio technology experience as described in experiment one. Only those with four years total experience or more were asked to participate in the full experiment.

A total of twenty subjects participated in the full study. All were volunteers and were not compensated for their time with money or course credit.

B. Apparatus

Audio playback was presented over the same Tannoy System 10 DMT II speaker as experiment one. It was powered this time by the 12 ohms rated channel A of a Yamaha SR-50 surround amplifier. The same laptop from experiment one was used to manage stimuli playback and record subject responses. The sound output was first fed to a Behringer Eurorack MX 1602 mixer, the output of which was connected to the amplifier. An optical mouse was connected to the computer for the subjects use when making their responses.

The room used for this experiment is located in Northwestern’s Music Administration Building is used for music cognition experiments. This room was somewhat smaller than that used in experiment one and resulted in closer distances for listening. Subjects were asked to sit facing the single speaker approximately 35 inches in front of them, with the center of the speaker cone 47.5 inches off the ground. The chair was of such height that the center of the speaker of the speaker was approximately the same height of the subjects' heads. The computer was placed to the left of the seating position on top of a table that was 27 inches high so that nothing was between the subject and speaker. We do not believe that these differences in rooms had any effect on the results given that the walls of both rooms were constructed of acoustically absorbent materials to make them as neutral as possible and only note the differences here to be complete.

C. Stimulus materials

Eighteen stimuli were produced, resulting from the same bell and vocal recordings from experiment one each being processed by a new set of nine parameter settings. These stimuli were again created using a Max/MSP patch written by the author.

The sample offset was again set at 200 ms without any randomization and a Gaussian window applied to the grains. A pitch multiplier of 1.0 was used without any randomization in this value. A granular period of 75 ms was used without any randomization applied to this parameter. Specific pairings of grain length and randomization were the only parameters that were varied in the creation of these stimuli (see Table 2-1). The randomization was expressed as a percentage of the grain length value within the Max/MSP patch. This percentage represents the total range, both positive and negative, that the value was allowed to fluctuate. This means that a 100 percent bandwidth applied to a grain length of 50 ms would have a maximum length of 75 ms and a minimum of 25 ms. The randomization was a simple, uniform distribution random number generator included in the Max/MSP set of included externals.

We decided it was necessary to make these stimuli slightly longer than those used in experiment one because of the addition of randomization. With these random fluctuations in length it simply took more repetitions to hear the random changes that were taking place. Therefore, each stimulus for experiment two was one second long with a 100 ms linear fade-in and 100 ms linear fade-out. The resulting sound files were normalized and converted using the same applications as experiment one.

D. Procedure

The procedure was the same as that used in experiment one.

E. Results

Subjects were grouped according to the operational definitions for electroacoustic listeners and composers developed before the experiments were conducted using their responses to the pre-experiment survey. Their responses were also used to divide them into halves according to the rules described in experiment one. For this experiment, subjects who responded with 4 or more to the first question were classified as being in the upper half of the listener respondents. Those that responded with 4 or more to the second question were classified as being in the upper half of the composer respondents. The number of subjects in each group was much closer to even than in experiment one (see Table 2-4a) using both the operational definitions and halving method.

In an analysis of all grouping variables and the corresponding intersections, no significance was found ($df = 8$, $p>0.05$; see Table 2-4b). This again means that no sub-populations were found with respect to electroacoustic listening or composition. The similarity judgments were therefore treated as coming from a single population and averaged together to form a single triangular matrix for analysis using multi-dimensional scaling.

The multi-dimensional scaling solutions were produced using the same procedures described in experiment one. The stress for the two-dimensional solution was again low ($stress = 0.13045$) and accounted for a high amount of the variation ($RSQ = 0.92762$). This means that slightly more that 92.7% of the variance in subjects' similarity ratings was accounted for in the graphing solution produced (see Graph 2-2). The three-dimensional solution showed a similar decrease in stress ($stress = 0.08268$) and increase in the variance accounted for ($RSQ = 0.96403$) to those observed in experiment one. It was very promising that the three-dimensional MDS graphing solution could account for 96.4% of the variation in this experiment (see Graph 2-3).

We again noted the apparent organization of the first dimension in both the two- and three-dimensional coordinates according to the source timbre used for processing the stimuli (see Table 2-5b). This time the bell source resulted in negative values and the vocal source in positive values, but the orientation of MDS solutions is not of importance in MDS solutions. So we may conclude that even with the addition of parameter randomization, subjects exhibited no confusion between the source samples being used.

Again, we will reserve further analysis of correlation between MDS dimensions and processing parameters until the final analysis of all three experiments.

VI. Experiment Three

The last in this series of three experiments focused on the granular period and random fluctuations in this parameter. Using a single grain length, a series of three periods used in experiment one was combined with specific settings for the amount of randomization allowed. This series of nine settings (Table 3-1) was used to process the same two timbres used in the previous experiments to produce the 18 stimuli used in this experiment.

Groupings related to electroacoustic experience were again analyzed for significance before producing MDS solutions based on the similarity ratings offered by subjects in this experiment.

A. Subjects

Potential subjects were drawn from the student population in the Audio Arts and Acoustics department at Columbia College Chicago and asked the same assessment questions as those in experiments one and two. Only those with four or more years of total experience were asked to participate in the full experiment. None of the subjects in experiment three had participated in experiment one.

A total of twenty-two subjects participated in the full study. All were volunteers and were not compensated for their time with money or course credit.

B. Apparatus

The apparatus was the same as that used in experiment one.

C. Stimulus materials

Eighteen stimuli were produced, resulting from the same bell and vocal recordings from experiments one and two each being processed by a new set of nine parameter settings. These stimuli were again created using a Max/MSP patch written by the author.

The sample offset and pitch multiplier were the same as those used in experiments one and two. A grain length of 29 ms was used without any randomization applied to this parameter. Specific pairings of granular period and randomization were the only variable parameters among the experiment three stimuli (see Table 3-1). The period randomization was also expressed as a percentage of the granular period value, just as the length randomization had been specified in terms of the grain length. Because of the randomization, these stimuli were the same length and used the same amplitude envelope as those in experiment two. The resulting sound files were normalized and converted using the same applications as experiment one and two.

D. Procedure

The procedure was the same as that used in experiments one and two.

E. Results

Subjects were again divided according to their responses to the two electroacoustic experience questions in the pre-experiment survey. Both operational definitions and the halving method described for experiment one were used as between-subject variables. Subjects who responded with 20 or more to the listening experience question were placed in the upper half of the respondents. Those that responded with 10 or more to the composition experience question were placed in the upper half of the respondents for this experiment. These divisions were used as grouping variables (see Table 3-4a) to test for any possible significance related to differences in experience with electroacoustic music.

As with the first two experiments, no significant difference was found according to these variables ($df = 7$, $p>0.05$; see Table 3-4b). This once again allowed us to treat the subjects as members of a single population and average their responses together into a single triangular matrix.

The multi-dimensional scaling solutions were produced using the same method as experiments one and two. The two-dimensional solution showed low stress (*stress = 0.12129*) and accounted for a high amount of variation (*RSQ = 0.95711*), the best values seen for these measures among the three experiments. The three-dimensional solution also resulted in the best measurements of stress (*stress = 0.07481*) and variance accounted for (*RSQ = 0.97175*). It was very promising to have MDS solutions that could account for 95.7% of the variance in two dimensions (see Graph 3-2) and 97.1% of the variance in three dimensions (see Graph 3-3).

As was observed in experiments one and two, the first dimension in each solution appears to correspond with timbre of the processing (see Table 3-5b). Again, it appears that the processing had no confusing effect on the perception of the source timbre used in producing these stimuli.

A more complete analysis of the connection between these MDS solutions and the processing parameters used follows.

VII. Analysis

Visual analysis of the MDS solutions yielded limited information beyond the apparent relationship between the first dimension and source timbre that has already been noted. The solutions from experiment one appear to show a relationship between the period and length manipulations and the other dimensions. The judgments from experiments two and three produce solutions that appear to show different relationships between the randomization and that parameter being randomized. In the two-dimensional solution from experiment two (see Graph 2-2) appears to show increases in length randomization extending upward across the second dimension. By comparison, the two-dimensional solution from experiment three (see Graph 3-2) appears to show increases in period randomization grouping toward the middle of that second dimension. Beyond this, it becomes difficult to speculate what these differences mean through a simple visual analysis.

In order to gain a better idea of what processing parameters correlated to the dimensions present in these graphs, we set about listing possible ways of expressing the parameters that were being manipulated in each experiment. Some of these have significance because they have been used in other pieces of software and others were simply observed as having possible relevance by the author. These parameters were then handled as variables and run through a statistical analysis for their possible correlation to the multi-dimensional scaling coordinates derived in both the two- and three-dimensional solutions for each experiment. This method was employed in one of the timbre perception studies we previously mentioned (Iverson and Krumhansl 1993). However in that study, since the stimuli were actual recordings of acoustical sources, information derived from spectral analysis of the recordings was used as the dataset against which the MDS solutions were tested. While such spectral analysis may provide a possible source of further analysis in the case of these experiments, we will be presenting here an analysis of granular processing parameters used to produce the stimuli.

For experiment one, we developed a list (see Table 1-5a) of not only the grain length and granular period being manipulated directly, but also the length-to-period ratio that results from the manipulation of these two parameters. Since there is no randomization present in the granular period, we also examined this parameter in terms of the frequency it produced, as well as that frequency multiplied by the length-to-period ratio. These parameters were analyzed for possible statistically significant correlation between themselves and each of the five dimensions resulting from the two- and three-dimensional MDS solutions (see Table 1-5b). Each was analyzed using the Pearson, Kendall's tau and Spearman's rho tests for correlation (see Tables 1-6a, b, c).

The second dimension for both the two- and three-dimensional solutions was found to have significant correlation ($p<0.001$) with the grain length, granular period and grain period expressed as frequency parameters in all three tests. Of these, the grain length exhibited the highest value for correlation in both the three-dimensional (*Pearson = 0.8980, Kendall = 0.8131, Spearman = 0.9148*) and two-dimensional (*Pearson = 0.8889, Kendall = 0.7986, Spearman = 0.9042*) solutions. The grain length parameter also showed an improvement in correlation between the two MDS solutions. We interpreted this to mean that the added dimension improved the representation of this parameter in the MDS solution.

The third dimension is for this MDS solution was found to have significant correlation ($p<0.001$) in all three tests with only the length-to-period ratio multiplied by the frequency. A second parameter, the length-to-period ratio, was found to have significant correlation ($p<0.001$) in only the Pearson test. Although significant, the actual correlation values (*Pearson = 0.8340, Kendall = 0.6333,* *Spearman = 0.8046*) were less than all three of those parameters that showed significant correlation in the second dimensions of these MDS solutions.

Note that both of the parameters that were manipulated directly in producing the stimuli correlated with a single dimension in the MDS solutions. This seems to suggest that their perception is linked somehow in the context of this experiment. We will look to the results of our analysis from experiments two and three for more information on how these parameters are perceived, since they were manipulated independently in those experiments without any variation in the other.

For the second experiment, we produced a list (see Table 2-5a) that contained the grain length, granular period and length-to-period ratio to start our analysis. The amount of length randomization was expressed not only as a bandwidth percentage of the length, as it was in the software used to produce the stimuli, but also the same bandwidth expressed in the milliseconds difference, the percentage-bandwidth-to-length ratio and ms-bandwidth-to-length ratio. Finally, the minimum and maximum possible lengths produced by the randomization were listed.

These parameters were again tested for correlation to the coordinates from the MDS solutions produced for this experiment (see Table 2-5b) using the same tests used for the first experiment results (see Tables 2-6a, b, c).

For experiment two, the second dimension for both the two- and three-dimensional MDS solutions was found to have significant correlation ($p<0.001$) with the all parameters except the granular period, length bandwidth expressed in ms and the length maximum in all three tests. Of the significant parameters, the length minimum showed the highest level of correlation for both the three-dimensional (*Pearson = -0.8691, Kendall = -0.7950, Spearman = -0.9083*) and two-dimensional solutions (*Pearson = -0.8584, Kendall = -0.7950, Spearman = -0.9083*) in all three tests. Unlike the first experiment's results, the correlation only showed improvement in between the different solutions in the Pearson test.

The third dimension of experiment two's MDS solution showed significant correlation ($p<0.01$) to the length minimum parameter. Although this correlation is at a slightly lower level of significance and correlation (*Pearson = 0.7961, Kendall = 0.5390, Spearman = 0.6926*), it is still the only parameter to show this level of correlation.

As with experiment one, most of the parameters correlated to the second dimension of the MDS solutions. Part of this can be accounted for in that some of these parameters are related and are themselves correlated to each other. The correlation values for both length and length-to-period ratio are equivalent in all three tests of both solutions (2D: *Pearson = -0.8050, Kendall = -0.7157, Spearman = -0.8262*; 3D: *Pearson = -0.8022, Kendall = -0.7157, Spearman = -0.8262*), but this is to be expected since the period is not changing. Because of this, all of the variance in the ratio can be attributed to the changes in length. Even the amount of randomization is a function of the length in the original software that produced these stimuli, specified as a bandwidth function related to a percentage of the grain length. Considering these relationships helps to explain some of the overlap seen in the test for significant correlations, and underscores the importance of finding the one parameter that is most highly correlated to a given dimension.

With this point clear, it interesting that the minimum and maximum lengths possible at the various levels of randomization found in the stimuli had the highest levels of correlation to the second and third dimensions respectively. This would seem to suggest that subjects most clearly perceived the boundaries of the randomization in the length. It is as if the initial grain length is secondary to their perception of the randomization applied to this parameter. Remember, our visual analysis of the MDS solutions for experiments two and three seemed to suggest that there was some difference in the subjects' perception of randomization in the length and period parameters. Analyzing the third experiment for correlations between processing parameters and MDS dimensions and then comparing those results to our findings for experiment two will hopefully allow us to evaluate the validity of this initial assessment.

For the third experiment, the list (see Table 3-5a) contained the same basic parameters as the first two in grain length, granular period and length-to-period ratio. The period randomization was characterized by parameters similar to those relating to length in experiment two. These were the randomization bandwidth expressed as a percentage of the period, bandwidth in terms of milliseconds difference, the percentage-bandwidth-to-period ratio, ms-bandwidth-to-period ratio, period minimum and period maximum.

Once again, these parameters were tested for correlation to the coordinates from the MDS solutions produced for this experiment (see Table 3-5b) using the same tests used in the other two (see Tables 3-6a, b, c).

The second dimension of the MDS solutions for experiment two showed significant correlation ($p<0.001$) with just the granular period and length-to-period ratio. Only the Pearson test showed a difference between the correlation of the period (2D: *correlation = 0.8126*, 3D: *correlation = -0.8192*) and length-to-period ratio (2D: *correlation = -0.8072*, 3D: *correlation = 0.8163*) in each solution. The only difference between the two parameter correlations in the Kendall and Spearman tests is the fact that they are the inverse of each other. As we have stated before, these parameters are related and this is likely the reason that they are both closely correlated.

The third dimension showed significant correlation ($p<0.001$) with the remaining parameters in the Pearson test. In the Kendall and Spearman tests, the percentage-bandwidth-to-period ratio failed to show significance at that level. All three tests showed the bandwidth in terms of milliseconds difference had the highest level of correlation (*Pearson = -0.9114, Kendall = -0.7881, Spearman = -0.9153*) with this third dimension. It seems that the initial period and the randomization applied were perceived separately in this case. This is certainly different than the findings of experiment two, where the MDS solutions seemed to express the boundaries of the randomization.

The reason for this difference can only be speculated upon at this point. Recall from the first experiment that the highest level of correlation was attributed to length in those MDS solutions. If we interpret this as meaning that it was the most important characteristic in the subjects' difference evaluations, how does that relate to the findings from the other two experiments? The second experiment dealt only with changes in length and we believe showed that the randomization was so disruptive as to become the primary phenomenon in shaping our subjects' responses. The third experiment had stimuli with only changes in the periodicity of granular onsets. Here the addition of randomization was separate from the perception of period and not as disruptive. This difference between the results of the last two experiments may be seen as reinforcing length as the primary processing parameter perceived in granular processing. If more importance is given to length, than it would make sense that the addition of randomization would be more disruptive to its perception than it was in the case of period.

How these different processing parameters are manifested in the sonic output may also shed some light on the different effects each has on upon perception of the results. The grain length is most likely to effect the spectra of the sound, becoming more broadband as it is shortened. This would place its perception most closely to that of timbre and studying more of the research in this area may help us to further interpret our findings. The grain onset period could be expressed as frequency, but it would be a frequency below the threshold of pitch perception. Because of this, it would most likely be analogous to tempo and may engage some of the same perception mechanisms. More research will be required in order to draw connections between these results and existing literature on the perception of these musical attributes.

Further correlations may found if the acoustic characteristics of the stimuli were to be analyzed and tested against the coordinates from the MDS solution. Items such as centroid frequency may exhibit significant correlation with the MDS coordinates. Since these are stimuli of finite length, we could also analyze them to determine the actual number of grains presented in each example and test for correlation with the MDS solution. Both of these and others will be pursued as this research continues to develop.

Also worth noting is that none of the parameters showed significant correlation ($p>0.05$) with the first dimension of any solution for all three experiments. This helps to affirm our visual analysis that the first dimension is related to the timbre source used in processing and that no parameters interfered with the subjects' perception of the difference between them.

VIII. Conclusion

This study explores new territory in music perception in by targeting sounds that are produced through granular processing. We had the added objective of applying the results of this study to the development of a new user interface. As we look forward to the work ahead, it becomes necessary to summarize the findings of these experiments.

First, it was clear from the multi-dimensional scaling solution that subjects were able to make significant distinctions between the various processing parameters used. Especially in the first experiment, clear patterns were visible in the MDS solution. The organization seemed to differ between the second and third experiments, suggesting that randomization of grain length and grain period were perceived differently by subjects.

Second, this difference in the visual analysis was confirmed by a statistical analysis of the correlation between the MDS dimensions and the parameters used to create the stimuli. The dimensions of the length randomization solution correlated most highly with to the minimum and maximum value present. In contrast, the period randomization results were correlated with the central value and the width of the stochastic deviations allowed.

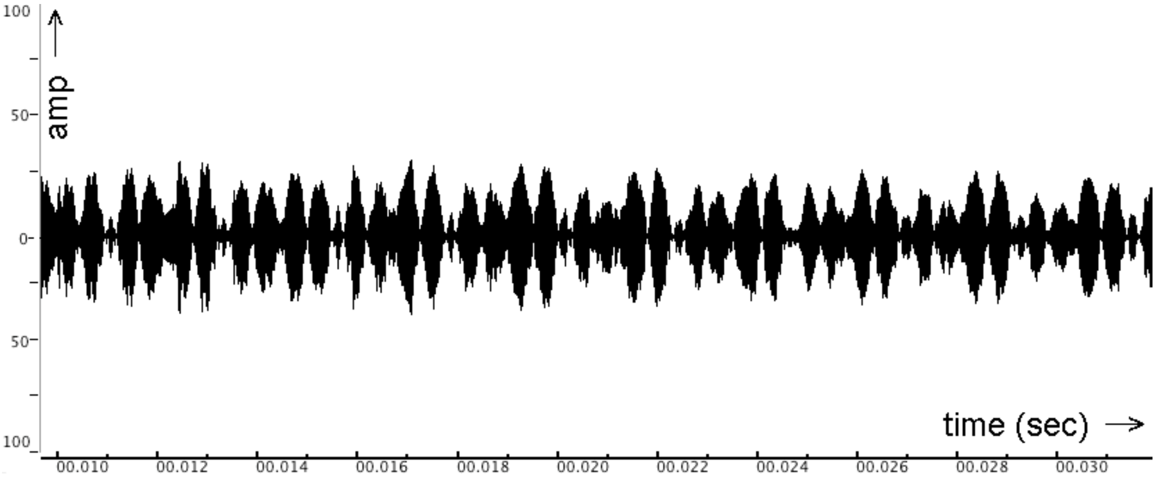
Third, the sources used to create the stimuli had a large effect on the MDS solutions. In all three experiments, timbre was clearly the cause of separation along the first dimension. Because its effects, it was somewhat difficult to review the effects of differences caused by the processing parameters. Because of this, any future studies undertaken to study would likely benefit from putting this issue aside thereby enabling the sole focus to be placed on granular processing parameters.

Lastly, no significant difference was found between the subjects according to their reported experience levels with electroacoustic listening and composing. The fact that no difference was found should not be interpreted as applying to the population as a whole. We continue to seek a better method for testing these difference since we expected to find some difference between these groups.

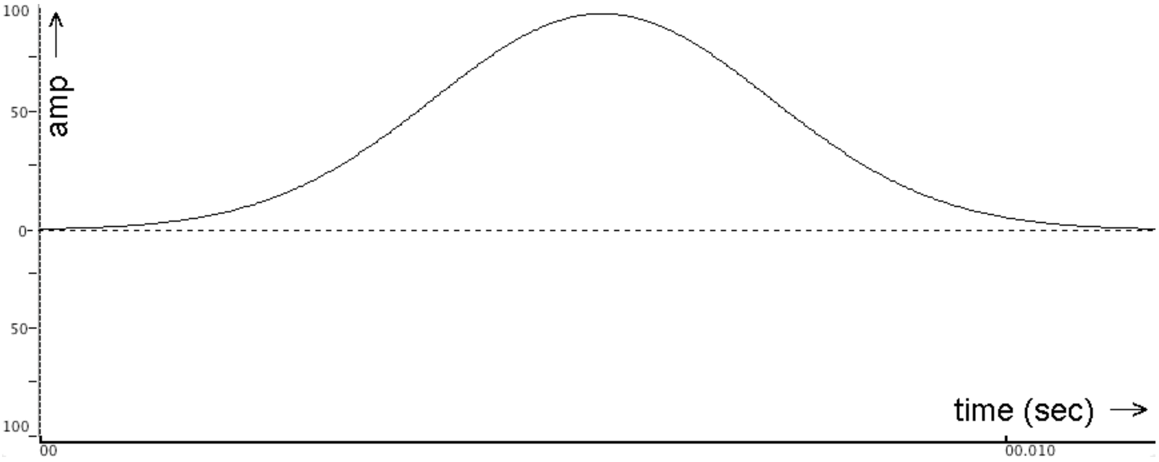
Overall we feel that these experiments were a successful beginning to the study of granular sounds and will provide useful information in the development of a simplified user interface.

Charts and Graphs

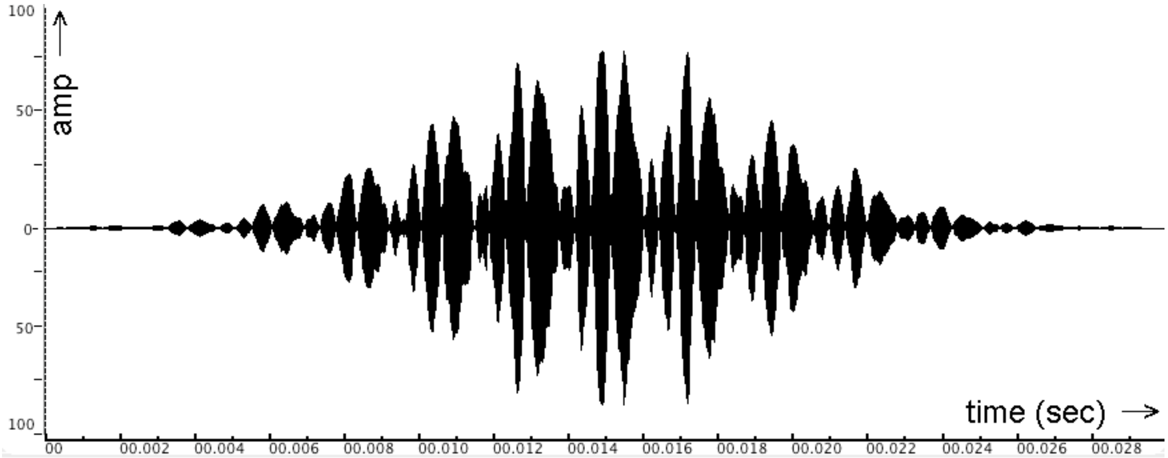
Graph 0-1. Approximately 20 ms from a recording of a handbell.



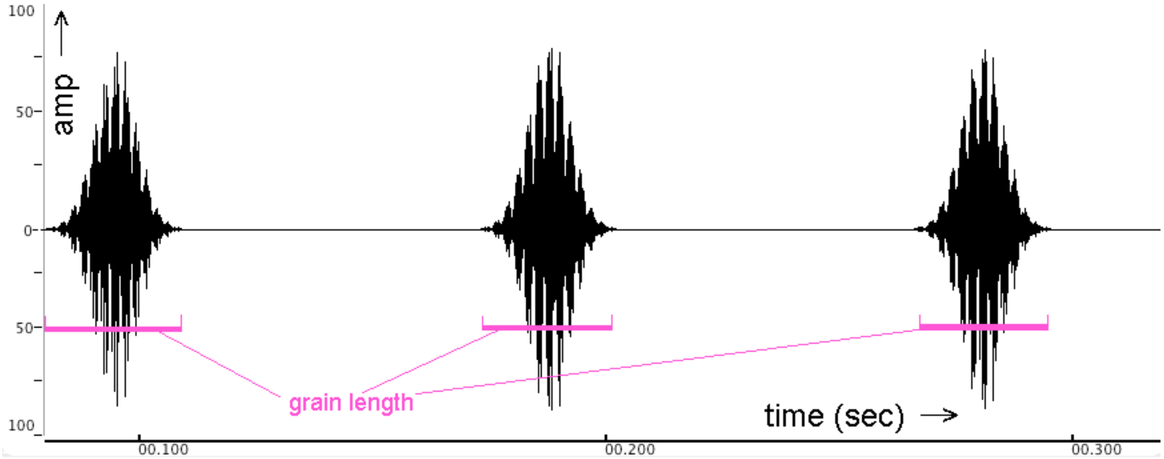
Graph 0-2. A Gaussian amplitude envelop.



Graph 0-3. A single grain combining the source in graph 0-1 and the envelop in graph 0-2.



Graph 0-5. Grain length is the duration of each of these sound events.



Graph 0-5. Grain period is the amount of times between consecutive grain onsets.

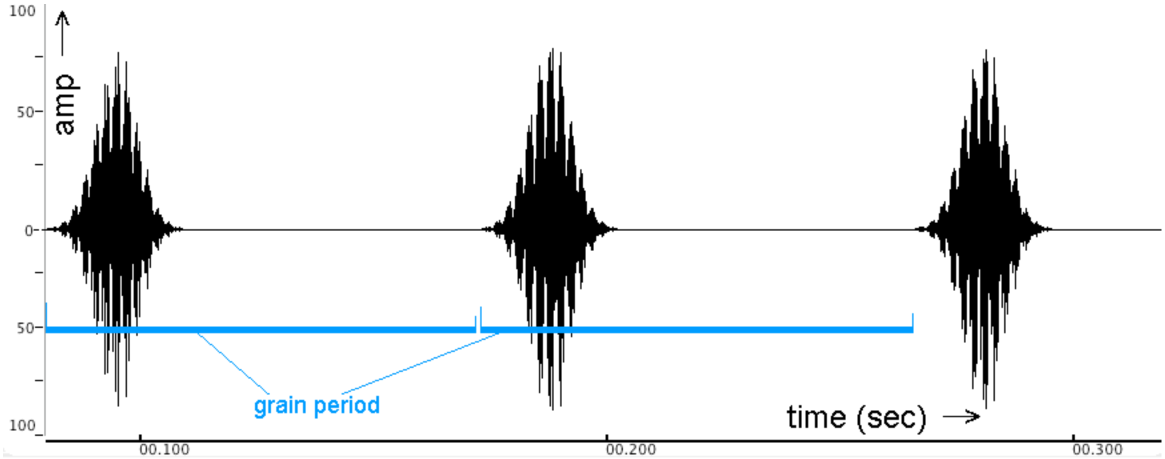


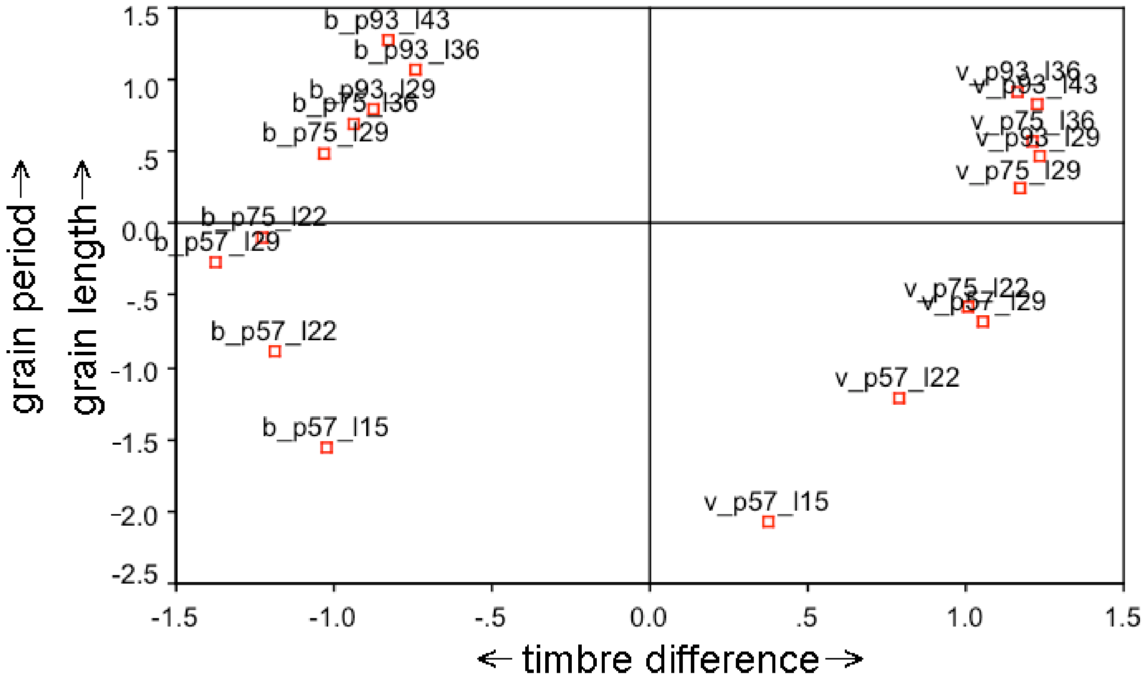
Table 0-6. Average similarity ratings offered when comparing the three original source timbres processed by granular software.

	flute	**vox_e**	**bell**
flute	27.3		
vox_e	357.3	29.5	
bell	330.9	405.9	53.2

Table 1-1. List of granular periods and grain lengths used in generating stimuli for experiment one.

length	period
15	57
22	57
29	57
22	75
29	75
36	75
29	93
36	93
43	93

Graph 1-2. Two-dimensional MDS solution for experiment one.



Graph 1-3. Three-dimensional MDS solution for experiment one.

Derived Stimulus Configuration

Euclidean distance model

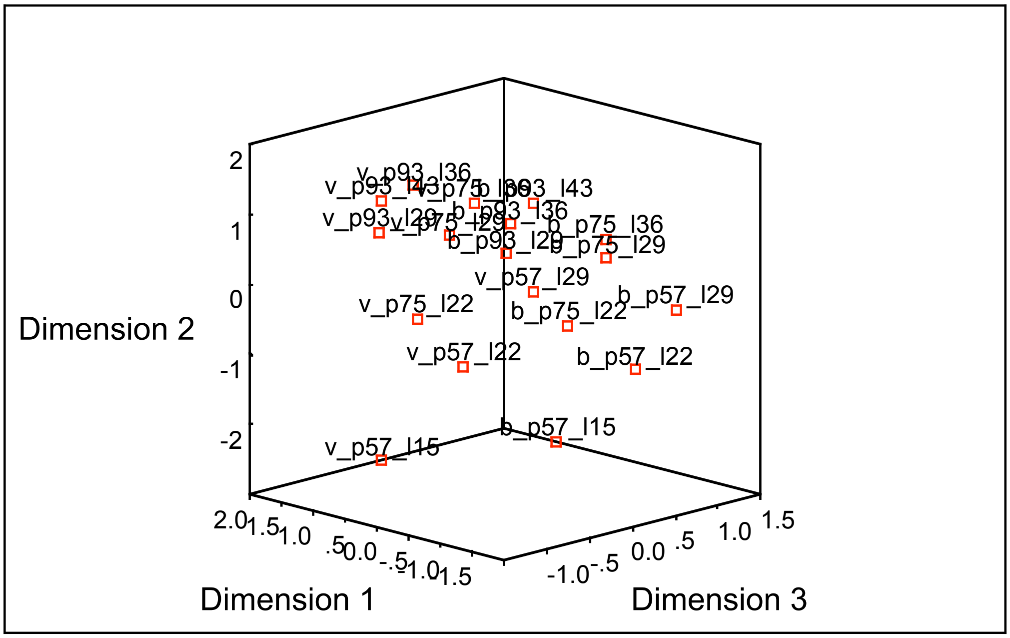


Table 1-4a. Number of members for each of the electroacoustic listener and composer groupings for experiment one.

		N
EA Listener od	no	3
	yes	17
EA Composer od	no	13
	yes	7
EA Listener halves	no	12
	yes	8
EA Composer halves	no	11
	yes	9

Table 1-4b. Test for between subject significance according to electroacoustic listener and composer groupings for experiment one.

Effect		Value	df	Hypothesis df	Error df	Sig.
EAL_OD	Pillai's Trace	0.931949192	6	13	1	0.652310218
	Wilks' Lambda	0.068050808	6	13	1	0.652310218
	Hotelling's Trace	13.69490261	6	13	1	0.652310218
	Roy's Largest Root	13.69490261	6	13	1	0.652310218
EAC_OD	Pillai's Trace	0.938184331	6	13	1	0.628432431
	Wilks' Lambda	0.061815669	6	13	1	0.628432431
	Hotelling's Trace	15.17712819	6	13	1	0.628432431
	Roy's Largest Root	15.17712819	6	13	1	0.628432431
EAL_OD * EAC_OD	Pillai's Trace	0	6	0	0	.
	Wilks' Lambda	1	6	0	7	.
	Hotelling's Trace	0	6	0	2	.
	Roy's Largest Root	0	6	13	0	.
EAL_HALF	Pillai's Trace	0.959131705	6	13	1	0.530041728
	Wilks' Lambda	0.040868295	6	13	1	0.530041728
	Hotelling's Trace	23.46884555	6	13	1	0.530041728
	Roy's Largest Root	23.46884555	6	13	1	0.530041728
EAC_HALF	Pillai's Trace	0.99665497	6	13	1	0.16222158
	Wilks' Lambda	0.00334503	6	13	1	0.16222158
	Hotelling's Trace	297.9509992	6	13	1	0.16222158
	Roy's Largest Root	297.9509992	6	13	1	0.16222158
EAL_HALF * EAC_HALF	Pillai's Trace	0	6	0	0	.
	Wilks' Lambda	1	6	0	7	.
	Hotelling's Trace	0	6	0	2	.
	Roy's Largest Root	0	6	13	0	.

Table 1-5a. List of possible parameters to correlate with the MDS solution from experiment one.

Reference number	Source timbre	Grain length	Granular period	Length to period ratio	Period expressed as frequency	Length to period ratio * frequency
1	bell	15	57	0.263157895	17.54385965	4.616805171
2	bell	22	57	0.385964912	17.54385965	6.771314251
3	bell	29	57	0.50877193	17.54385965	8.92582333
4	bell	22	75	0.293333333	13.33333333	3.911111111
5	bell	29	75	0.386666667	13.33333333	5.155555556
6	bell	36	75	0.48	13.33333333	6.4
7	bell	29	93	0.311827957	10.75268817	3.352988785
8	bell	36	93	0.387096774	10.75268817	4.162330905
9	bell	43	93	0.462365591	10.75268817	4.971673026
10	vox_e	15	57	0.263157895	17.54385965	4.616805171
11	vox_e	22	57	0.385964912	17.54385965	6.771314251
12	vox_e	29	57	0.50877193	17.54385965	8.92582333
13	vox_e	22	75	0.293333333	13.33333333	3.911111111
14	vox_e	29	75	0.386666667	13.33333333	5.155555556
15	vox_e	36	75	0.48	13.33333333	6.4
16	vox_e	29	93	0.311827957	10.75268817	3.352988785
17	vox_e	36	93	0.387096774	10.75268817	4.162330905
18	vox_e	43	93	0.462365591	10.75268817	4.971673026

Table 1-5b. List of coordinates from the two- and three-dimensional MDS solutions for experiment one.

Reference number	MDS dimension 1 of 3	MDS dimension 2 of 3	MDS dimension 3 of 3	MDS dimension 1 of 2	MDS dimension 2 of 2
1	-1.2117	-1.8621	-0.3043	-1.0257	-1.5496
2	-1.4207	-1.0299	0.4597	-1.1913	-0.8899
3	-1.5275	-0.2751	0.8593	-1.3714	-0.2728
4	-1.4453	-0.1292	-0.3491	-1.2241	-0.093
5	-1.2347	0.5813	0.2664	-1.0285	0.495
6	-1.1192	0.8075	0.3429	-0.9368	0.6883
7	-0.9666	0.8852	-0.7131	-0.8772	0.8009
8	-0.8405	1.2408	-0.5721	-0.7408	1.0775
9	-0.9673	1.5199	-0.3845	-0.8282	1.278
10	0.4638	-2.2823	-1.0994	0.3717	-2.0708
11	0.9336	-1.4604	0.2185	0.7887	-1.2114
12	1.0402	-0.6919	1.1025	1.0575	-0.6841
13	1.2009	-0.7325	-0.1376	1.0047	-0.5839
14	1.3748	0.2522	0.3732	1.1685	0.2398
15	1.3702	0.6308	0.6576	1.2112	0.5725
16	1.4689	0.5101	-0.3633	1.2312	0.4617
17	1.4103	1.0795	-0.0163	1.1646	0.9156
18	1.4707	0.9563	-0.3404	1.2259	0.8261

Table 1-6a. Pearson's correlation between processing parameters and MDS solution coordinates for experiment one.

		mds dim 1 of 3	mds dim 2 of 3	mds dim 3 of 3	mds dim 1 of 2	mds dim 2 of 2
grain length	Pearson Correlation	0.1594	** 0.8980	0.1356	0.1567	** 0.8889
	Sig. (2-tailed)	0.5274	* 0.0000	0.5917	0.5346	* 0.0000
	N	18.0000	18.0000	18.0000	18.0000	18.0000
grain onset period	Pearson Correlation	0.1834	0.8607	-0.4405	0.1648	0.8657
	Sig. (2-tailed)	0.4664	* 0.0000	0.0673	0.5134	* 0.0000
	N	18.0000	18.0000	18.0000	18.0000	18.0000
length to period ratio	Pearson Correlation	0.0450	0.4372	0.7069	0.0605	0.4197
	Sig. (2-tailed)	0.8592	0.0697	* 0.0010	0.8115	0.0830
	N	18.0000	18.0000	18.0000	18.0000	18.0000
period as frequency	Pearson Correlation	-0.1836	-0.8735	0.4030	-0.1663	-0.8801
	Sig. (2-tailed)	0.4659	* 0.0000	0.0973	0.5097	* 0.0000
	N	18.0000	18.0000	18.0000	18.0000	18.0000
length to period ratio * freq	Pearson Correlation	-0.0879	-0.2444	** 0.8340	-0.0646	-0.2614
	Sig. (2-tailed)	0.7286	0.3283	* 0.0000	0.7990	0.2948
	N	18.0000	18.0000	18.0000	18.0000	18.0000

** Highest level of correlation for the given dimension.

* Significance at the p<0.001 level.

Table 1-6b. Kendall's tau_b correlation between processing parameters and MDS solution coordinates for experiment one.

		mds dim 1 of 3	mds dim 2 of 3	mds dim 3 of 3	mds dim 1 of 2	mds dim 2 of 2
grain length	Correlation Coefficient	0.2614	** 0.8131	0.0436	0.2759	** 0.7986
	Sig. (2-tailed)	0.1577	* 0.0000	0.8139	0.1359	* 0.0000
	N	18.0000	18.0000	18.0000	18.0000	18.0000
grain onset period	Correlation Coefficient	0.3734	0.7624	-0.4356	0.3267	0.7779
	Sig. (2-tailed)	0.0523	* 0.0001	0.0236	0.0896	* 0.0001
	N	18.0000	18.0000	18.0000	18.0000	18.0000
length to period ratio	Correlation Coefficient	0.0539	0.3638	0.4446	0.0808	0.3503
	Sig. (2-tailed)	0.7604	0.0395	0.0119	0.6473	0.0474
	N	18.0000	18.0000	18.0000	18.0000	18.0000
period as frequency	Correlation Coefficient	-0.3734	-0.7624	0.4356	-0.3267	-0.7779
	Sig. (2-tailed)	0.0523	* 0.0001	0.0236	0.0896	* 0.0001
	N	18.0000	18.0000	18.0000	18.0000	18.0000
length to period ratio * freq	Correlation Coefficient	-0.1886	-0.1752	** 0.6333	-0.1347	-0.1886
	Sig. (2-tailed)	0.2858	0.3216	* 0.0003	0.4458	0.2858
	N	18.0000	18.0000	18.0000	18.0000	18.0000

** Highest level of correlation for the given dimension.
* Significance at the p<0.001 level.

Table 1-6c. Spearman's rho correlation between processing parameters and MDS solution coordinates for experiment one.

		mds dim 1 of 3	mds dim 2 of 3	mds dim 3 of 3	mds dim 1 of 2	mds dim 2 of 2
grain length	Correlation Coefficient	0.3404	** 0.9148	0.0447	0.3510	** 0.9042
	Sig. (2-tailed)	0.1669	* 0.0000	0.8603	0.1532	* 0.0000
	N	18.0000	18.0000	18.0000	18.0000	18.0000
grain onset period	Correlation Coefficient	0.4328	0.8787	-0.5115	0.3934	0.8918
	Sig. (2-tailed)	0.0728	* 0.0000	0.0300	0.1062	* 0.0000
	N	18.0000	18.0000	18.0000	18.0000	18.0000
length to period ratio	Correlation Coefficient	0.0747	0.4977	0.5848	0.1203	0.4686
	Sig. (2-tailed)	0.7685	0.0356	0.0108	0.6345	0.0498
	N	18.0000	18.0000	18.0000	18.0000	18.0000
period as frequency	Correlation Coefficient	-0.4328	-0.8787	0.5115	-0.3934	-0.8918
	Sig. (2-tailed)	0.0728	* 0.0000	0.0300	0.1062	* 0.0000
	N	18.0000	18.0000	18.0000	18.0000	18.0000
length to period ratio * freq	Correlation Coefficient	-0.2364	-0.2530	** 0.8046	-0.1742	-0.2820
	Sig. (2-tailed)	0.3450	0.3111	* 0.0001	0.4894	0.2569
	N	18.0000	18.0000	18.0000	18.0000	18.0000

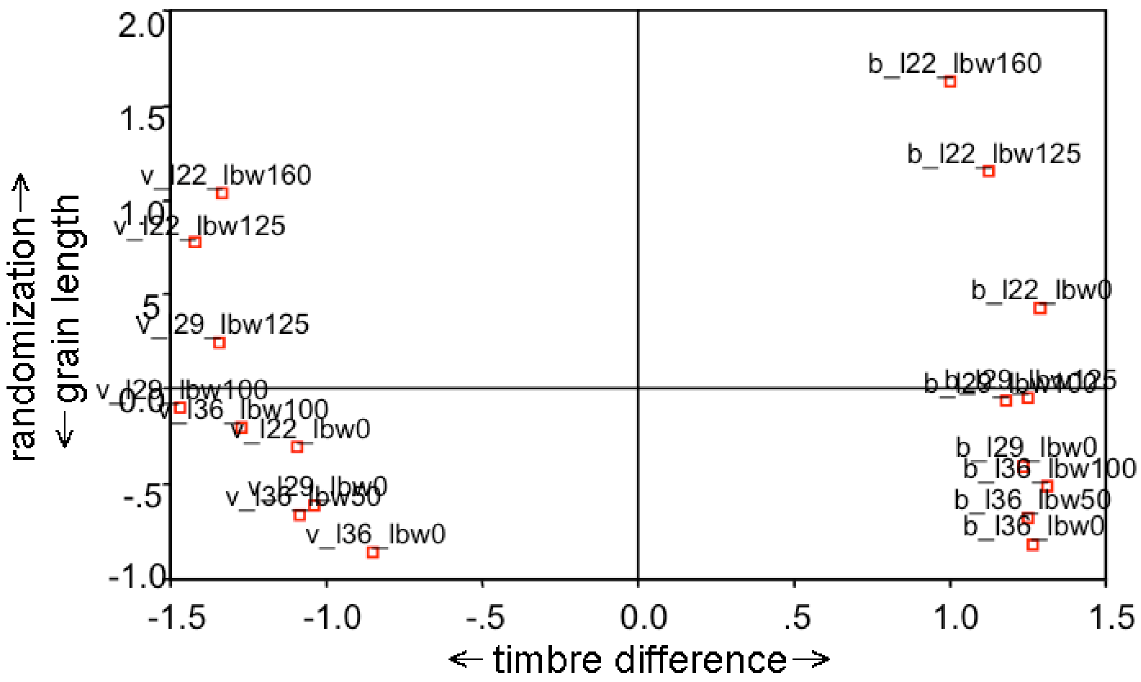
** Highest level of correlation for the given dimension.

* Significance at the $p<0.001$ level.

Table 2-1. List of grain length and length bandwidths used in generating stimuli for experiment two.

length	bandwidth
22	0
22	125
22	160
29	0
29	100
29	125
36	0
36	50
36	100

Graph 2-2. Two-dimensional MDS solution for experiment two.



Graph 2-3. Three-dimensional MDS solution for experiment two.

Derived Stimulus Configuration

Euclidean distance model

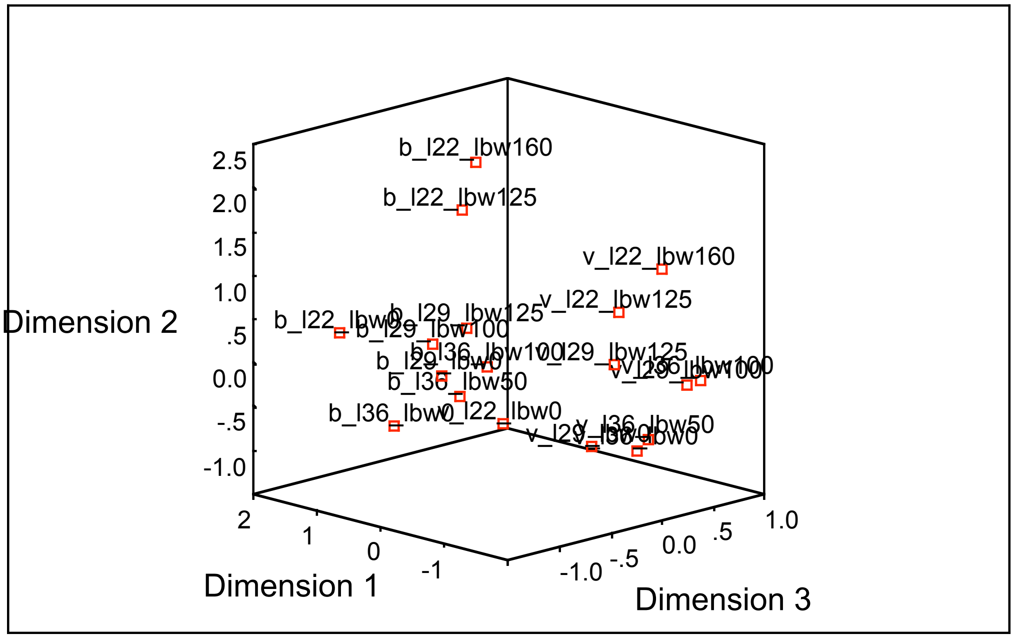


Table 2-4a. Number of members for each of the electroacoustic listener and composer groupings for experiment two.

		N
EA Listener od	no	12
	yes	8
EA Composer od	no	12
	yes	8
EA Listener halves	no	9
	yes	11
EA Composer halves	no	9
	yes	11

Table 2-4b. Test for between subject significance according to electroacoustic listener and composer groupings for experiment two.

Effect		Value	df	Hypothesis df	Error df	Sig.
EAL_OD	Pillai's Trace	0.995932063	8	11	1	0.163990947
	Wilks' Lambda	0.004067937	8	11	1	0.163990947
	Hotelling's Trace	244.8248401	8	11	1	0.163990947
	Roy's Largest Root	244.8248401	8	11	1	0.163990947
EAC_OD	Pillai's Trace	0.933433453	8	11	1	0.605266775
	Wilks' Lambda	0.066566547	8	11	1	0.605266775
	Hotelling's Trace	14.0225607	8	11	1	0.605266775
	Roy's Largest Root	14.0225607	8	11	1	0.605266775
EAL_OD * EAC_OD	Pillai's Trace	0.927489091	8	11	1	0.626354954
	Wilks' Lambda	0.072510909	8	11	1	0.626354954
	Hotelling's Trace	12.79102838	8	11	1	0.626354954
	Roy's Largest Root	12.79102838	8	11	1	0.626354954
EAL_HALF	Pillai's Trace	0.982646254	8	11	1	0.332070832
	Wilks' Lambda	0.017353746	8	11	1	0.332070832
	Hotelling's Trace	56.62444742	8	11	1	0.332070832
	Roy's Largest Root	56.62444742	8	11	1	0.332070832
EAC_HALF	Pillai's Trace	0.955081918	8	11	1	0.51302032
	Wilks' Lambda	0.044918082	8	11	1	0.51302032
	Hotelling's Trace	21.26274918	8	11	1	0.51302032
	Roy's Largest Root	21.26274918	8	11	1	0.51302032
EAL_HALF * EAC_HALF	Pillai's Trace	0.995650884	8	11	1	0.169492532
	Wilks' Lambda	0.004349116	8	11	1	0.169492532
	Hotelling's Trace	228.9317606	8	11	1	0.169492532
	Roy's Largest Root	228.9317606	8	11	1	0.169492532

Table 2-5a. List of possible parameters to correlate with the MDS solution from experiment two.

Reference number	Source timbre	Grain length	Granular period	Length to period ratio	Length randomization bandwidth (% of length)	Length randomization bandwidth (length in ms)	Bandwidth percent to grain length ratio	Bandwidth length to grain length ratio	Grain length minimum	Grain length maximum
1	bell	22	75	0.293333333	0	0	0	0	22	22
2	bell	22	75	0.293333333	125	27.5	5.681818182	1.25	8.25	35.75
3	bell	22	75	0.293333333	160	35.2	7.272727273	1.6	4.4	39.6
4	bell	29	75	0.386666667	0	0	0	0	29	29
5	bell	29	75	0.386666667	100	29	3.448275862	1	14.5	43.5
6	bell	29	75	0.386666667	125	36.25	4.310344828	1.25	10.875	47.125
7	bell	36	75	0.48	0	0	0	0	36	36
8	bell	36	75	0.48	50	18	1.388888889	0.5	27	45
9	bell	36	75	0.48	100	36	2.777777778	1	18	54
10	vox_e	22	75	0.293333333	0	0	0	0	22	22
11	vox_e	22	75	0.293333333	125	27.5	5.681818182	1.25	8.25	35.75
12	vox_e	22	75	0.293333333	160	35.2	7.272727273	1.6	4.4	39.6
13	vox_e	29	75	0.386666667	0	0	0	0	29	29
14	vox_e	29	75	0.386666667	100	29	3.448275862	1	14.5	43.5
15	vox_e	29	75	0.386666667	125	36.25	4.310344828	1.25	10.875	47.125
16	vox_e	36	75	0.48	0	0	0	0	36	36
17	vox_e	36	75	0.48	50	18	1.388888889	0.5	27	45
18	vox_e	36	75	0.48	100	36	2.777777778	1	18	54

Table 2-5b. List of coordinates from the two- and three- dimensional MDS solutions for experiment two.

Reference number	MDS dimension 1 of 3	MDS dimension 2 of 3	MDS dimension 3 of 3	MDS dimension 1 of 2	MDS dimension 2 of 2
1	1.3792	0.3229	-1.0506	1.2881	0.4327
2	1.3758	1.3623	0.148	1.1272	1.156
3	1.2299	1.924	0.2065	1.0009	1.6241
4	1.4801	-0.5016	0.0179	1.2354	-0.4072
5	1.4169	-0.0902	-0.1004	1.1809	-0.0621
6	1.4919	-0.0428	0.283	1.2498	-0.0473
7	1.4912	-0.9551	-0.4431	1.2651	-0.8145
8	1.5021	-0.8046	0.2007	1.2512	-0.681
9	1.542	-0.5571	0.5045	1.3087	-0.5106
10	-1.1633	-0.2416	-1.0431	-1.093	-0.3092
11	-1.7159	0.9009	-0.2509	-1.4207	0.7715
12	-1.6055	1.2285	0.2349	-1.3352	1.0314
13	-1.2597	-0.7232	-0.23	-1.0352	-0.6142
14	-1.7507	-0.1181	0.4005	-1.4712	-0.102
15	-1.6195	0.2785	-0.2347	-1.342	0.255
16	-1.0307	-0.9935	0.3597	-0.851	-0.8568
17	-1.3081	-0.7814	0.2877	-1.0824	-0.6697
18	-1.4558	-0.2079	0.7094	-1.2765	-0.1959

Table 2-6a. Pearson's correlation between processing parameters and MDS solution coordinates for experiment two.

		mds dim 1 of 3	mds dim 2 of 3	mds dim 3 of 3	mds dim 1 of 2	mds dim 2 of 2
grain length	Pearson Correlation	0.0584	-0.8022	0.4907	0.0584	-0.8050
	Sig. (2-tailed)	0.8180	* 0.0001	0.0387	0.8180	* 0.0001
	N	18.0000	18.0000	18.0000	18.0000	18.0000
grain onset period	Pearson Correlation	.(a)	.(a)	.(a)	.(a)	.(a)
	Sig. (2-tailed)	.	.	.	.	.
	N	18.0000	18.0000	18.0000	18.0000	18.0000
length to period ratio	Pearson Correlation	0.0584	-0.8022	0.4907	0.0584	-0.8050
	Sig. (2-tailed)	0.8180	* 0.0001	0.0387	0.8180	* 0.0001
	N	18.0000	18.0000	18.0000	18.0000	18.0000
length bandwidth percent	Pearson Correlation	-0.0875	0.7298	0.4852	-0.0924	0.7138
	Sig. (2-tailed)	0.7298	* 0.0006	0.0412	0.7155	* 0.0009
	N	18.0000	18.0000	18.0000	18.0000	18.0000
length bandwidth ms	Pearson Correlation	-0.0763	0.5246	0.5892	-0.0818	0.5086
	Sig. (2-tailed)	0.7634	0.0254	0.0101	0.7471	0.0312
	N	18.0000	18.0000	18.0000	18.0000	18.0000
bw percent to length ratio	Pearson Correlation	-0.0898	0.8473	0.3753	-0.0939	0.8320
	Sig. (2-tailed)	0.7231	* 0.0000	0.1249	0.7109	* 0.0000
	N	18.0000	18.0000	18.0000	18.0000	18.0000
bw ms to length ratio	Pearson Correlation	-0.0875	0.7298	0.4852	-0.0924	0.7138
	Sig. (2-tailed)	0.7298	* 0.0006	0.0412	0.7155	* 0.0009
	N	18.0000	18.0000	18.0000	18.0000	18.0000
length minimum	Pearson Correlation	0.0927	** -0.8691	-0.1708	0.0969	** -0.8584
	Sig. (2-tailed)	0.7145	* 0.0000	0.4979	0.7021	* 0.0000
	N	18.0000	18.0000	18.0000	18.0000	18.0000
length maximum	Pearson Correlation	-0.0271	-0.0639	** 0.7961	-0.0316	-0.0790
	Sig. (2-tailed)	0.9151	0.8010	* 0.0001	0.9009	0.7553
	N	18.0000	18.0000	18.0000	18.0000	18.0000

** Highest level of correlation for the given dimension.
* Significance at the p<0.001 level.

Table 2-6b. Kendall's tau_b correlation between processing parameters and MDS solution coordinates for experiment two.

		mds dim 1 of 3	mds dim 2 of 3	mds dim 3 of 3	mds dim 1 of 2	mds dim 2 of 2
grain length	Correlation Coefficient	0.2489	-0.7157	0.4045	0.2178	-0.7157
	Sig. (2-tailed)	0.1958	* 0.0002	0.0356	0.2577	* 0.0002
	N	18.0000	18.0000	18.0000	18.0000	18.0000
grain onset period	Correlation Coefficient	.	.	.	.	.
	Sig. (2-tailed)	.	.	.	.	.
	N	18.0000	18.0000	18.0000	18.0000	18.0000
length to period ratio	Correlation Coefficient	0.2489	-0.7157	0.4045	0.2178	-0.7157
	Sig. (2-tailed)	0.1958	* 0.0002	0.0356	0.2577	* 0.0002
	N	18.0000	18.0000	18.0000	18.0000	18.0000
length bandwidth percent	Correlation Coefficient	-0.2033	0.6534	0.2178	-0.2614	0.6534
	Sig. (2-tailed)	0.2718	* 0.0004	0.2391	0.1577	* 0.0004
	N	18.0000	18.0000	18.0000	18.0000	18.0000
length bandwidth ms	Correlation Coefficient	-0.1126	0.3518	0.3941	-0.1689	0.3518
	Sig. (2-tailed)	0.5342	0.0521	0.0296	0.3512	0.0521
	N	18.0000	18.0000	18.0000	18.0000	18.0000
bw percent to length ratio	Correlation Coefficient	-0.2252	0.6896	0.1689	-0.2815	0.6896
	Sig. (2-tailed)	0.2138	* 0.0001	0.3512	0.1202	* 0.0001
	N	18.0000	18.0000	18.0000	18.0000	18.0000
bw ms to length ratio	Correlation Coefficient	-0.2033	0.6534	0.2178	-0.2614	0.6534
	Sig. (2-tailed)	0.2718	* 0.0004	0.2391	0.1577	* 0.0004
	N	18.0000	18.0000	18.0000	18.0000	18.0000
length minimum	Correlation Coefficient	0.2425	** -0.7950	-0.0539	0.2830	** -0.7950
	Sig. (2-tailed)	0.1699	* 0.0000	0.7604	0.1093	* 0.0000
	N	18.0000	18.0000	18.0000	18.0000	18.0000
length maximum	Correlation Coefficient	0.0539	-0.0674	** 0.5390	-0.0135	-0.0674
	Sig. (2-tailed)	0.7604	0.7030	0.0023	0.9392	0.7030
	N	18.0000	18.0000	18.0000	18.0000	18.0000

** Highest level of correlation for the given dimension.

* Significance at the $p<0.001$ level.

Table 2-6c. Spearman's rho correlation between processing parameters and MDS solution coordinates for experiment two.

		mds dim 1 of 3	mds dim 2 of 3	mds dim 3 of 3	mds dim 1 of 2	mds dim 2 of 2
grain length	Correlation Coefficient	0.3016	-0.8262	0.4984	0.2623	-0.8262
	Sig. (2-tailed)	0.2238	* 0.0000	0.0353	0.2930	* 0.0000
	N	18.0000	18.0000	18.0000	18.0000	18.0000
grain onset period	Correlation Coefficient	.	.	.	.	.
	Sig. (2-tailed)	.	.	.	.	.
	N	18.0000	18.0000	18.0000	18.0000	18.0000
length to period ratio	Correlation Coefficient	0.3016	-0.8262	0.4984	0.2623	-0.8262
	Sig. (2-tailed)	0.2238	* 0.0000	0.0353	0.2930	* 0.0000
	N	18.0000	18.0000	18.0000	18.0000	18.0000
length bandwidth percent	Correlation Coefficient	-0.2702	0.7595	0.2957	-0.3404	0.7595
	Sig. (2-tailed)	0.2782	* 0.0003	0.2335	0.1669	* 0.0003
	N	18.0000	18.0000	18.0000	18.0000	18.0000
length bandwidth ms	Correlation Coefficient	-0.1308	0.4893	0.4935	-0.2151	0.4893
	Sig. (2-tailed)	0.6050	0.0393	0.0374	0.3913	0.0393
	N	18.0000	18.0000	18.0000	18.0000	18.0000
bw percent to length ratio	Correlation Coefficient	-0.2995	0.7804	0.2573	-0.3670	0.7804
	Sig. (2-tailed)	0.2273	* 0.0001	0.3026	0.1341	* 0.0001
	N	18.0000	18.0000	18.0000	18.0000	18.0000
bw ms to length ratio	Correlation Coefficient	-0.2702	0.7595	0.2957	-0.3404	0.7595
	Sig. (2-tailed)	0.2782	* 0.0003	0.2335	0.1669	* 0.0003
	N	18.0000	18.0000	18.0000	18.0000	18.0000
length minimum	Correlation Coefficient	0.3235	** -0.9083	-0.1037	0.3650	** -0.9083
	Sig. (2-tailed)	0.1904	* 0.0000	0.6822	0.1364	* 0.0000
	N	18.0000	18.0000	18.0000	18.0000	18.0000
length maximum	Correlation Coefficient	0.0664	-0.0871	** 0.6926	-0.0249	-0.0871
	Sig. (2-tailed)	0.7936	0.7311	0.0014	0.9219	0.7311
	N	18.0000	18.0000	18.0000	18.0000	18.0000

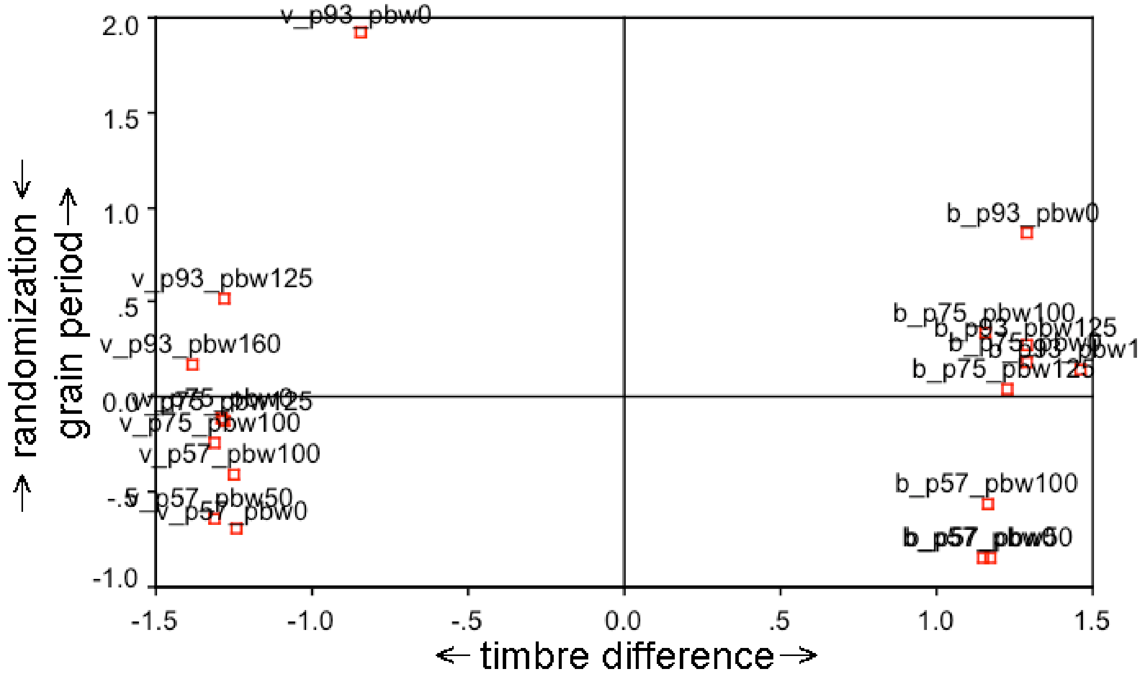
** Highest level of correlation for the given dimension.

* Significance at the $p<0.001$ level.

Table 3-1. List of granular periods and period bandwidths used in generating stimuli for experiment three.

period	bandwidth
57	0
57	50
57	100
75	0
75	100
75	125
93	0
93	125
93	160

Graph 3-2. Two-dimensional MDS solution for experiment one.



Graph 3-3. Three-dimensional MDS solution for experiment three.

Derived Stimulus Configuration

Euclidean distance model

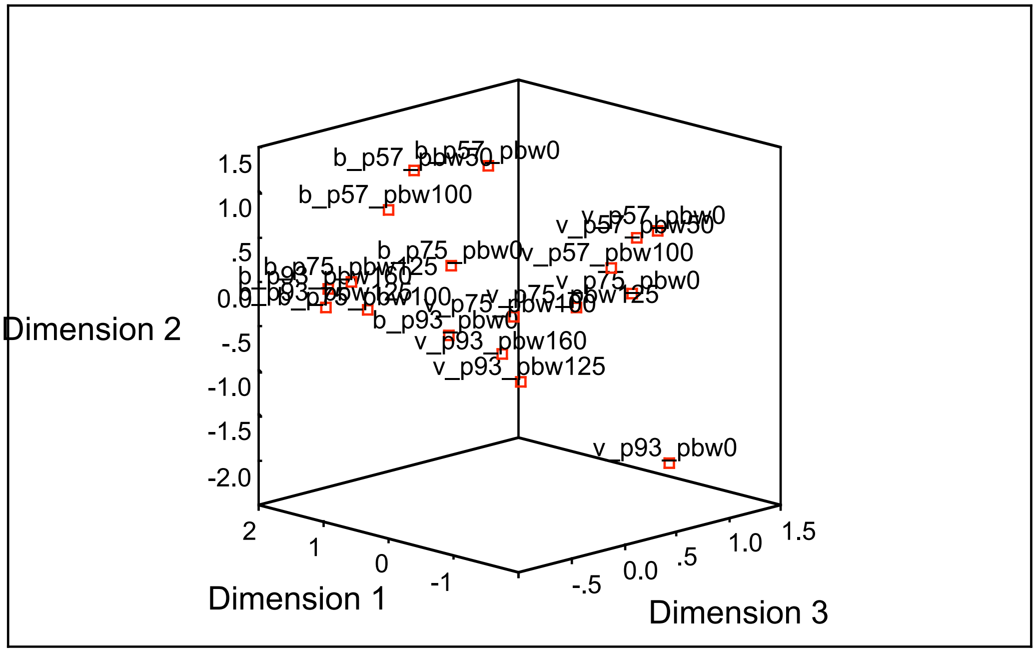


Table 3-4a. Number of members for each of the electroacoustic listener and composer groupings for experiment three.

		N
EA Listener od	no	5
	yes	17
EA Composer od	no	9
	yes	13
EA Listener halves	no	11
	yes	11
EA Composer halves	no	12
	yes	10

Table 3-4b. Test for between subject significance according to electroacoustic listener and composer groupings for experiment three.

Effect		Value	df	Hypothesis df	Error df	Sig.
EAL_OD	Pillai's Trace	0.983777841	7	14	1	0.361688302
	Wilks' Lambda	0.016222159	7	14	1	0.361688302
	Hotelling's Trace	60.64407755	7	14	1	0.361688302
	Roy's Largest Root	60.64407755	7	14	1	0.361688302
EAC_OD	Pillai's Trace	0.997107681	7	14	1	0.15680859
	Wilks' Lambda	0.002892319	7	14	1	0.15680859
	Hotelling's Trace	344.7433652	7	14	1	0.15680859
	Roy's Largest Root	344.7433652	7	14	1	0.15680859
EAL_OD * EAC_OD	Pillai's Trace	0.99211712	7	14	1	0.256317317
	Wilks' Lambda	0.00788288	7	14	1	0.256317317
	Hotelling's Trace	125.8571826	7	14	1	0.256317317
	Roy's Largest Root	125.8571826	7	14	1	0.256317317
EAL_HALF	Pillai's Trace	0.971482793	7	14	1	0.468162857
	Wilks' Lambda	0.028517207	7	14	1	0.468162857
	Hotelling's Trace	34.06654776	7	14	1	0.468162857
	Roy's Largest Root	34.06654776	7	14	1	0.468162857
EAC_HALF	Pillai's Trace	0.987622767	7	14	1	0.318334232
	Wilks' Lambda	0.012377233	7	14	1	0.318334232
	Hotelling's Trace	79.79350447	7	14	1	0.318334232
	Roy's Largest Root	79.79350447	7	14	1	0.318334232
EAL_HALF * EAC_HALF	Pillai's Trace	0.925841403	7	14	1	0.692449186
	Wilks' Lambda	0.074158597	7	14	1	0.692449186
	Hotelling's Trace	12.48461334	7	14	1	0.692449186
	Roy's Largest Root	12.48461334	7	14	1	0.692449186

Table 3-5a. List of possible parameters to correlate with the MDS solution from experiment three.

Reference number	Source timbre	Grain length	Granular period	Length to period ratio	Period randomization bandwidth (% of period)	Period randomization bandwidth (length in ms)	Bandwidth percent to period ratio	Bandwidth length to period ratio	Period minimum	Period maximum
1	bell	29	57	0.50877193	0	0	0	0	57	57
2	bell	29	57	0.50877193	50	28.5	0.877192982	0.5	42.75	71.25
3	bell	29	57	0.50877193	100	57	1.754385965	1	28.5	85.5
4	bell	29	75	0.386666667	0	0	0	0	75	75
5	bell	29	75	0.386666667	100	75	1.333333333	1	37.5	112.5
6	bell	29	75	0.386666667	125	93.75	1.666666667	1.25	28.125	121.875
7	bell	29	93	0.311827957	0	0	0	0	93	93
8	bell	29	93	0.311827957	125	116.25	1.344086022	1.25	34.875	151.125
9	bell	29	93	0.311827957	160	148.8	1.720430108	1.6	18.6	167.4
10	vox_e	29	57	0.50877193	0	0	0	0	57	57
11	vox_e	29	57	0.50877193	50	28.5	0.877192982	0.5	42.75	71.25
12	vox_e	29	57	0.50877193	100	57	1.754385965	1	28.5	85.5
13	vox_e	29	75	0.386666667	0	0	0	0	75	75
14	vox_e	29	75	0.386666667	100	75	1.333333333	1	37.5	112.5
15	vox_e	29	75	0.386666667	125	93.75	1.666666667	1.25	28.125	121.875
16	vox_e	29	93	0.311827957	0	0	0	0	93	93
17	vox_e	29	93	0.311827957	125	116.25	1.344086022	1.25	34.875	151.125
18	vox_e	29	93	0.311827957	160	148.8	1.720430108	1.6	18.6	167.4

Table 3-5b. List of coordinates from the two- and three-dimensional MDS solutions for experiment three.

Reference number	MDS dimension 1 of 3	MDS dimension 2 of 3	MDS dimension 3 of 3	MDS dimension 1 of 2	MDS dimension 2 of 2
1	1.3107	0.8943	0.7776	1.1463	-0.8501
2	1.4036	1.0115	0.1184	1.1734	-0.8414
3	1.3937	0.6626	-0.1411	1.1659	-0.5564
4	1.5015	-0.1895	0.5365	1.2927	0.1877
5	1.3681	-0.3955	-0.3537	1.1588	0.3375
6	1.4313	-0.0524	-0.4567	1.2233	0.0453
7	1.5201	-0.963	0.5142	1.2862	0.8631
8	1.4735	-0.2881	-0.673	1.2898	0.2698
9	1.7141	-0.1798	-0.5198	1.4631	0.1516
10	-1.4579	0.7276	0.6549	-1.2446	-0.6959
11	-1.5696	0.7291	0.3996	-1.315	-0.6434
12	-1.508	0.4607	0.1794	-1.251	-0.4029
13	-1.5331	0.114	0.3584	-1.2892	-0.115
14	-1.4963	0.1853	-0.7494	-1.3127	-0.2368
15	-1.5389	0.1202	-0.1759	-1.279	-0.1271
16	-0.9946	-2.0793	1.0565	-0.8475	1.9167
17	-1.4794	-0.5665	-0.6537	-1.278	0.5195
18	-1.5384	-0.1912	-0.8723	-1.3826	0.1778

Table 3-6a. Pearson's correlation between processing parameters and MDS solution coordinates for experiment three.

		mds dim 1 of 3	mds dim 2 of 3	mds dim 3 of 3	mds dim 1 of 2	mds dim 2 of 2
grain length	Pearson Correlation	.(a)	.(a)	.(a)	.(a)	.(a)
	Sig. (2-tailed)	.	.	.	.	.
	N	18.0000	18.0000	18.0000	18.0000	18.0000
grain onset period	Pearson Correlation	0.0522	** -0.8192	-0.3730	0.0466	** 0.8126
	Sig. (2-tailed)	0.8371	* 0.0000	0.1274	0.8544	* 0.0000
	N	18.0000	18.0000	18.0000	18.0000	18.0000
length to period ratio	Pearson Correlation	-0.0487	0.8163	0.3932	-0.0435	-0.8072
	Sig. (2-tailed)	0.8477	* 0.0000	0.1064	0.8640	* 0.0001
	N	18.0000	18.0000	18.0000	18.0000	18.0000
period bandwidth percent	Pearson Correlation	-0.0121	0.0269	-0.9076	-0.0179	-0.0272
	Sig. (2-tailed)	0.9621	0.9157	* 0.0000	0.9439	0.9147
	N	18.0000	18.0000	18.0000	18.0000	18.0000
period bandwidth ms	Pearson Correlation	-0.0040	-0.0742	** -0.9114	-0.0105	0.0709
	Sig. (2-tailed)	0.9873	0.7698	* 0.0000	0.9669	0.7799
	N	18.0000	18.0000	18.0000	18.0000	18.0000
bw percent to period ratio	Pearson Correlation	-0.0210	0.1620	-0.8247	-0.0255	-0.1572
	Sig. (2-tailed)	0.9341	0.5206	* 0.0000	0.9201	0.5334
	N	18.0000	18.0000	18.0000	18.0000	18.0000
bw ms to period ratio	Pearson Correlation	-0.0121	0.0269	-0.9076	-0.0179	-0.0272
	Sig. (2-tailed)	0.9621	0.9157	* 0.0000	0.9439	0.9147
	N	18.0000	18.0000	18.0000	18.0000	18.0000
period minimum	Pearson Correlation	0.0379	-0.4402	0.7890	0.0417	0.4398
	Sig. (2-tailed)	0.8813	0.0675	* 0.0001	0.8696	0.0678
	N	18.0000	18.0000	18.0000	18.0000	18.0000
period maximum	Pearson Correlation	0.0188	-0.3955	-0.8242	0.0117	0.3903
	Sig. (2-tailed)	0.9411	0.1043	* 0.0000	0.9634	0.1093
	N	18.0000	18.0000	18.0000	18.0000	18.0000

** Highest level of correlation for the given dimension.

* Significance at the $p<0.001$ level.

Table 3-6b. Kendall’s tau_b correlation between processing parameters and MDS solution coordinates for experiment three.

		mds dim 1 of 3	mds dim 2 of 3	mds dim 3 of 3	mds dim 1 of 2	mds dim 2 of 2
grain length	Correlation Coefficient	.	.	.	.	.
	Sig. (2-tailed)	.	.	.	.	.
	N	18.0000	18.0000	18.0000	18.0000	18.0000
grain onset period	Correlation Coefficient	0.2178	-0.7779	-0.3578	0.1400	0.7624
	Sig. (2-tailed)	0.2577	* 0.0001	0.0630	0.4669	* 0.0001
	N	18.0000	18.0000	18.0000	18.0000	18.0000
length to period ratio	Correlation Coefficient	-0.2178	0.7779	0.3578	-0.1400	-0.7624
	Sig. (2-tailed)	0.2577	* 0.0001	0.0630	0.4669	* 0.0001
	N	18.0000	18.0000	18.0000	18.0000	18.0000
period bandwidth percent	Correlation Coefficient	-0.0145	-0.1742	-0.7551	-0.0290	0.1888
	Sig. (2-tailed)	0.9374	0.3463	* 0.0000	0.8753	0.3076
	N	18.0000	18.0000	18.0000	18.0000	18.0000
period bandwidth ms	Correlation Coefficient	0.0000	-0.2252	** -0.7881	-0.0281	0.2392
	Sig. (2-tailed)	1.0000	0.2138	* 0.0000	0.8765	0.1866
	N	18.0000	18.0000	18.0000	18.0000	18.0000
bw percent to period ratio	Correlation Coefficient	-0.0563	0.0563	-0.5066	-0.0281	-0.0422
	Sig. (2-tailed)	0.7560	0.7560	0.0052	0.8765	0.8157
	N	18.0000	18.0000	18.0000	18.0000	18.0000
bw ms to period ratio	Correlation Coefficient	-0.0145	-0.1742	-0.7551	-0.0290	0.1888
	Sig. (2-tailed)	0.9374	0.3463	* 0.0000	0.8753	0.3076
	N	18.0000	18.0000	18.0000	18.0000	18.0000
period minimum	Correlation Coefficient	0.0808	-0.0269	0.5794	0.0404	0.0135
	Sig. (2-tailed)	0.6473	0.8788	* 0.0010	0.8191	0.9392
	N	18.0000	18.0000	18.0000	18.0000	18.0000
period maximum	Correlation Coefficient	0.1078	-0.4581	-0.6333	0.0674	0.4716
	Sig. (2-tailed)	0.5419	0.0095	* 0.0003	0.7030	0.0076
	N	18.0000	18.0000	18.0000	18.0000	18.0000

** Highest level of correlation for the given dimension.

* Significance at the $p<0.001$ level.

Table 3-6c. Spearman's rho correlation between processing parameters and MDS solution coordinates for experiment three.

		mds dim 1 of 3	mds dim 2 of 3	mds dim 3 of 3	mds dim 1 of 2	mds dim 2 of 2
grain length	Correlation Coefficient	.	.	.	.	.
	Sig. (2-tailed)	.	.	.	.	.
	N	18.0000	18.0000	18.0000	18.0000	18.0000
grain onset period	Correlation Coefficient	0.2623	-0.8918	-0.4066	0.1705	0.8787
	Sig. (2-tailed)	0.2930	* 0.0000	0.0941	0.4988	* 0.0000
	N	18.0000	18.0000	18.0000	18.0000	18.0000
length to period ratio	Correlation Coefficient	-0.2623	0.8918	0.4066	-0.1705	-0.8787
	Sig. (2-tailed)	0.2930	* 0.0000	0.0941	0.4988	* 0.0000
	N	18.0000	18.0000	18.0000	18.0000	18.0000
period bandwidth percent	Correlation Coefficient	-0.0426	-0.1808	-0.8850	-0.0383	0.1681
	Sig. (2-tailed)	0.8669	0.4727	* 0.0000	0.8801	0.5050
	N	18.0000	18.0000	18.0000	18.0000	18.0000
period bandwidth ms	Correlation Coefficient	-0.0295	-0.2278	** -0.9153	-0.0422	0.2151
	Sig. (2-tailed)	0.9074	0.3633	* 0.0000	0.8680	0.3913
	N	18.0000	18.0000	18.0000	18.0000	18.0000
bw percent to period ratio	Correlation Coefficient	-0.0886	0.0337	-0.7002	-0.0464	-0.0422
	Sig. (2-tailed)	0.7267	0.8943	0.0012	0.8549	0.8680
	N	18.0000	18.0000	18.0000	18.0000	18.0000
bw ms to period ratio	Correlation Coefficient	-0.0426	-0.1808	-0.8850	-0.0383	0.1681
	Sig. (2-tailed)	0.8669	0.4727	* 0.0000	0.8801	0.5050
	N	18.0000	18.0000	18.0000	18.0000	18.0000
period minimum	Correlation Coefficient	0.1078	-0.0705	0.7672	0.0705	0.0912
	Sig. (2-tailed)	0.6702	0.7810	* 0.0002	0.7810	0.7188
	N	18.0000	18.0000	18.0000	18.0000	18.0000
period maximum	Correlation Coefficient	0.1161	-0.6428	-0.8004	0.0664	0.6262
	Sig. (2-tailed)	0.6463	0.0040	* 0.0001	0.7936	0.0054
	N	18.0000	18.0000	18.0000	18.0000	18.0000

** Highest level of correlation for the given dimension.

* Significance at the $p<0.001$ level.

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