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The effect of entropy and duration in the temporal perception of a sequence of sound events

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Abstract

Entropy has become important as a phenomenon of contemporaneity in art practice and theory. Since the composer Karlheinz Stockhausen stated the problem in his essay Structure and Experiential Time (1955), several authors focused their studies on the influence of the rate of auditory information in the perception of elapsed time. In this article the influence of physical duration and some aspects of entropy on perceived duration of a sound stimulus of about 35 s is studied. Dispersion of time interval between onset of events and the temporal density of events are aspects possibly related to the entropy. An experiment is conducted and preliminary results about the influence of entropy on the perception of duration are discussed.

Keywords: perceived duration, music entropy.

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1. Introduction

Aesthetic experiences in which sound is the modeled material can presuppose two ideal situations regarding the perception of time. The distribution of sound events in time can induce to one or other of these situations. In one of these situations, events can be associated with each other in a timeline that serves as reference. This case is commonly given in Western music tradition which proposes a careful listening from start to finish. Oppositely in the other situation, perception can not associate events so the listener cannot construct a timeline as a reference. This case is present in some Eastern music or those latest developments in the field of contemporary music in which the listener can escape and regain attention without losing the meaning of the expressed idea. Each piece of art whose material is the sound suggests a characteristic passage of time.

1.1. Timescales

Several authors have given different timescales relevant to psychoacoustics. Roederer [2] considers three scales, each of which corresponds to a particular "processing center" with a specific function in the auditory system. A "microscopic" scale, where the vibrations of sound waves occur. These are detected and coded in the inner ear, and lead mainly primary sensations as pitch, loudness and timbre. He proposes an "intermediate" scale represented by transient changes such as the attack or the decay of sounds.

> …sound stimuli seem to mainly affect processing mechanisms located in the neural path from the ear to the auditory area of the brain and provide additional keys used on discrimination, identification and perception of the quality of sounds. [2]

Finally he proposes a "macroscopic" scale that represents the durations of sound events, successions and rhythm. The process of this macroscopic information, which determines a musical message, takes place in the cerebral cortex (the highest level of the nervous system).

The psychological attributes related to auditory processing in the brain are difficult to identify and the higher the level of the processing, the harder to identify those attributes. Results seem to be influenced by learning and conditioned by culture, as well as by the psychological state of the individual.

The object of observation was the influence caused by the discontinuity and grouping, possibly as a consequence of random variation of the time interval between the onsets of consecutive events. Such influence is interpreted as the effect of entropy, given that the results are strictly valid only under the conditions of such experiences.

In this paper we conduct an experiment to study the influence of (1) rate of sound events per unit time, (2) the variance of the temporal interval between the onsets of consecutive events and (3) the physical duration of the complete sequence on the perceived duration of the complete sequence. Our goal is to study the effects of factors that are possibly related with the entropy of the musical message. In the second section, materials and methods of the experiment are described, in the third section the results are shown and a discussion is proposed, and the last section contains the conclusions.

2. Materials and methods

We worked on the macroscopic time scale varying only the temporal interval between the onsets of events and the duration of the complete sequence of events. To avoid the influence of other parameters, one type of event was used: a short bell sound. Pink noise was used as background.

2.1. Subjets

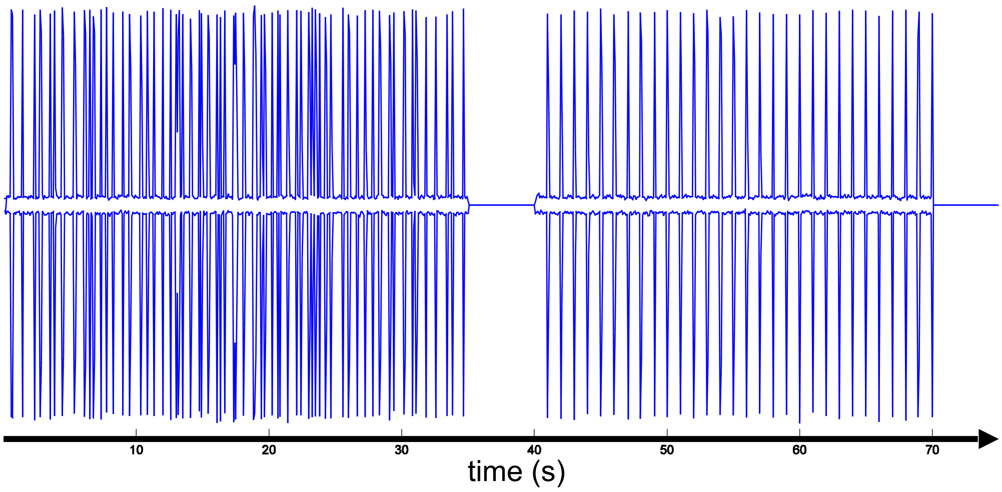
Regarding subject selection criteria, it was attempted to gather a homogeneous group with the intention of comparing subsequent results when the study extends to a larger and more heterogeneous group. Therefore, interest was focused on those subjects with interactive musical experience, so that all the individuals that collaborated in the experiment (a total of 18) are music students between 18 and 28 years old, with normal hearing capabilities. The subject selection was carried out under informed consent.

2.2. Stimuli

To use as stimuli, 30 audio signals of the same kind and with durations of between 30s and 40s were created. In all of them we used a continuous pink noise as a background.

We generated the stimuli signals using an algorithm implemented in a numerically oriented programming language. The algorithm uses a Gaussian random number generator routine to generate the temporal intervals between events. The random numbers are samples from a Gaussian distribution with known median (in this experiment C) and standard deviation (in this experiment σ). The onset time for each event is found accumulating the temporal intervals. The algorithm generates an audio file placing the sound event at each onset time. The time series of an anchor and a test signal are shown in Figure 1.

Figure 1: Time series of the anchor - test audio stimulus



The value for the parameters of each signal is shown in Table 1.

Table 1: Stimuli parameters

Stimuli	*T* (s)	*C* (#e/s)	*σ* (ms)
Anchor	35	2	195
Test 1	30	1	10
Test 2	30	1	150
Test 3	30	1	400
Test 4	40	1	10
Test 5	40	1	150
Test 6	40	1	400
Test 7	30	3	10
Test 8	30	3	150
Test 9	30	3	400
Test 10	40	3	10
Test 11	40	3	150
Test 12	40	3	400
Test 13	35	2	195
Test 14	35	2	195
Test 15	35	2	195

Notice that, even though the anchor signals have the same parameters (T, C and σ), they are different signals with different time series. Similarly the test signals 13, 14 and 15 have the same parameters than the anchor but they are all different signals with different time series. In 12 of the trials, the test signal was presented with 2 levels of T, 2 levels of C and 3 levels of σ. T levels are 30 s and 40 s, C levels are 1 and 3, and σ levels are 10 ms; 150 ms and 400 ms.

2.3. Experiment

For each test two stimuli of the same type were administered, separated by an equal time interval. The first is considered as anchor signal and the second as test signal. The method of forced choice was used, since the subject always had to give an answer about the test signal, and the question was: If the anchor signal has duration of 100%, which is the duration of the test signal? For a written response, a scale from 70% to 130% with steps of 5% was provided on printed paper. For each trial, the subject indicated the option with a cross in the appropriate box.

The same 15 trials were conducted for each subject and the total duration did not exceed 30 minutes per subject. The order of each test was randomized in order to eliminate the influence of accidental factors such as fluctuating attention, the preceding tests, the role of preconceptions, fatigue, etc.

A recorded voice with the indication of the number of test (eg, "Test No. 1") was presented to the subject before each trial. Subjects were asked to keep eyes closed during each test.

The equipment used during tests consisted of a computer with the *Reaper 64* audio playback software and a *Direct Sound Ex-29 Extreme Isolation* set of headphones. The experiment took place in silent classrooms at UNR and UNL.

3. Results and discussion

3.1. Results

The analysis of variance is shown in Table 2. The rate of sound events per unit time, the real duration and the interaction of standard deviation of the temporal interval between events with the rate of sound events per unit time, show a statistically significant ($\alpha<0.10$) effect on the perceived duration.

Table 2: Analysis of Variance (ANOVA) of a model with main factors and interactions

Factor	Sum Sq	DF	Mean Sq	F	pValue
C	533.33	1	533.33	4.027	0.046883
T	6378.7	1	6378.7	48.164	1.75×10^{-06}
σ	208.85	1	208.85	15.769	0.21149
C T	237.04	1	237.04	17.898	0.18332
C σ	537.05	1	537.05	40.551	0.046135
T σ	51.096	1	51.096	0.38581	0.53561
Error	16952	128	132.44		

The estimation of the coefficients for a linear regression model is shown in Table 3. Although the main effect of **σ** is not significant, we decided to maintain it in the model because the interaction ***C* σ** is significant ($\alpha<0.10$).

Table 3: Linear model fit regression

Factor	Estimate	SE	t-Stat	pValue
(Intercept)	39,5	8,62	4,59	$1{,}0 \times 10^{-5}$
C	4,8	1,69	2,83	0,005
T	1,5	0,22	6,93	$1{,}7 \times 10^{-10}$
σ	19,0	15,36	1,24	0,218
C σ	-13,8	6,87	-2,01	0,046

The model is

$$\frac{T_p}{35}100 = 39.5 + 4.8C + 1.5T + 19.0\sigma - 13.8C\sigma \qquad (1)$$

where T_p is the perceived duration in units equivalents to seconds referred to a phrase similar to an anchor.

3.2. Discussion

The results are a first approach to the problem. We do not intend to describe musical entropy but it could possibly be related with *C* and **σ**. And, as expected, *C* and **σ** are related to perceived duration of a musical phrase of about 35 s.

The model in (1) could be interpreted as follows. A musical phrase, similar to that of the experiment, with real duration *T* = 35 s, *C* = 1,95 s^{-1} and **σ = 80 ms** is perceived as a duration T_p = 35 s. In order to reach a perceived duration of T_p = 38 s the real duration could be raised to *T* = 40 s or the density of events raised to *C* = 3.9.

We rearranged our model in order to express the deviation of the temporal intervals as a portion (ϑ) of the mean temporal interval. Notice that the mean temporal interval is C^{-1} and $\vartheta = \sigma / C^{-1}$ is

$$\vartheta = C\sigma \tag{2}$$

that is equal to the interaction ***C σ*** of the previous model.

The new model is

$$\frac{T_p}{35}100 = 43.1 + 3.4C + 1.5T - 6.2\vartheta \tag{3}$$

The estimation of the coefficients for a linear regression model is shown in Table 4.

Table 4: Linear model fit regression

Factor	Estimate	SE	t-Stat	pValue
(Intercept)	43,1	8,1	5,29	5×10^{-7}
C	3,4	1,2	2,70	8×10^{-3}
T	1,5	0,2	6,92	1×10^{-10}
ϑ	-6,2	3,1	-2,02	0,046

4. Conclusions

In this paper we conduct an experiment to study the influence of factors that are possibly related to the entropy of musical fragments on perceived duration of a single sequence of about 35 s. The studied factors are the rate of events per unit time, the standard deviation of the temporal intervals between events and the real, or physical, duration. Although the sample is small, significant effects of two main factors and an interaction were found. As expected, the main effect on perceived duration at the studied levels is the real duration. The effect of the temporal density of events at the studied levels is also positive. The effect of the deviation of the temporal intervals is negative indicating a possible relation in the opposite direction with entropy and experiential time.

Future works could include a graphical scale for responses because we think it could be more intuitive than a percentage scale. Future experiments could gradually include melodies, rhythmic patterns, timbre variations, etc.

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