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The Informational Patterns of Laughter

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Abstract: Laughter is one of the most characteristic –and enigmatic– communicational traits of human individuals. Its analysis has to take into account a variety of emotional, social, cognitive, and communicational factors densely interconnected. In this article we study laughter just as an auditive signal (as a 'neutral' information carrier), and we compare its structure with the regular traits of linguistic signals. In the experimental records of human laughter that we have performed, the most noticeable trait is the disorder content of frequencies. In comparison with the sonograms of vowels, the information content of which appears as a characteristic, regular function of the first vibration modes of the dynamic system formed, for each vowel, by the vocal cords and the accompanying resonance of the vocalization apparatus, the sonograms of laughter are highly irregular. In the episodes of laughter, a highly random content in frequencies appears, reason why it cannot be considered as a genuine codification of patterned information like in linguistic signals. In order to numerically gauge the disorder content of laughter frequencies, we have performed several "entropy" measures of the spectra –trying to unambiguously identify spontaneous laughter from "faked", articulated laughter. Interestingly, Shannon's entropy (the most natural candidate) performs rather poorly.

Keywords: Information, Laughter, Sonograms, Plosives, Entropy of Laughter, Power Spectral Density.

A Brief Introduction to Laughter

Following several classic authors, we may describe human laughter as the vocal output of a "confluence" produced in a variety of social, emotional, cognitive, and communicational processes that somehow contain an abrupt transition or an opposition of evaluations, and are finally resolved into a cancellation of effective action (e.g., for Kant, laughter derives from "a sudden transformation of a strained expectation into nothing.") [1]. In a slightly different interpretation, we will consider here that laughter works as an automatic mechanism for the *ad hoc* minimization of a high level of neuronal excitation that circumstantially –suddenly– becomes irrelevant from the behavioral point of view as a focus of attention [2-4]. Thus, a potential problem, and so a focus of dedicated problem solving processes, is suddenly discarded by the laughing individual, and as a consequence the accompanying neuronal processes have to be cancelled or 'discharged' prematurely. This line of explanation is reminiscent of Zajonc's approach to emotional processes –e.g., his explanation of the regulation of facial blood flow in emotional expressions such as blushing and pallor, that are contributing to the appropriate level of brain irrigation; when we blush, for instance, there is a bypass of an unnecessary surge of brain blood related to a cancelled action of escape which is redirected towards the face [5,6].

In the case of laughter, its genuine meaning as a 'solved' problem is accompanied by the regular reward –or biological pleasure– that ensues the culmination of problem solving activities at any behavioral or cognitive level. So, laughter is pleasurable, and is actively looked upon by human subjects, although it contains that curious inner tension of opposed processes, seemingly beyond voluntary production. Human laughter is performed socially, in a sort of mutual administration of biological reward. It is a highly characteristic trait of human groups. Neurodynamically, laughter is also closely related to its opposite: crying [3,6]. They both appear evolutionarily as additional 'automatic' mechanisms cooperating in the social problem–solving of human groups (which approximately count three of four times more individuals than other anthropoid groups). There is good evidence (Bachorowsky, personal communication) that human laughter directly derives from the pre-laughter traits found in juvenile chimpanzees and gorillas, but applied to wider social contexts [1]. So, the evolutionary reutilization of the ancestral pathway used by primates for emotional communication in playful contexts, becomes transformed in an automatic minimization mechanism of neuronal excitation within human groups, paralleling the emergence of language [6]. We have to take into account that symbolic communication by means of language is a powerful problem-solving tool, but as the same time it is even more powerful as a trouble-making instrument. So the social need of additional problem solving tools, involuntary ones, leading to the resolution of social tensions and favoring the creation of inter-individual bonds.

In sum, laughter becomes a privileged channel to promote social bonding by reutilization of the pseudo–solution processes related to discarding communicative irrelevances, endowed with pleasurable reward. Laughter and crying contribute to the creation of powerful nexus in human groups, and are endowed with an intriguing background of associated molecular processes at the synaptic level. Laughter actively contributes to the fabrication of the most important 'memories' and bonds of human life: in between parents and children, in between sexual partners, and among the members of stable, close-knit groups [1,4, 7-9].

The Sonograms of Laughter

In relation with the possible orchestration of laughter out from the "old" primate emotion-expressing path [1, 10,11], we have already found in our initial analysis of laughter sonograms that there is a strong discrepancy in between the mathematical forms of laughter and language acoustic elements. Surprisingly, there seems to be few formal studies of laughter sonograms [1].

As can be easily appreciated, the occurring frequencies, the pauses, and the duration of the laughter bouts (plosives) are completely different between laughter and language, and this difference is a firm argument for attributing their activity to completely different neuronal systems. Even in the same individual, we confront two very different kinds of sonograms (see below, Figures 1, 2, and 3). The values corresponding to laughter are far more disperse and entropic than those of language. In a "voluntary" or non-spontaneous laughter the sonograms easily detect the presence of language ordered elements, and the relative absence of entropic or "chaotic" components.

Intuitively this difference is very easy to detect by any subject, just listening to the respective sounds. But, formally, things are more complicated. In this study we attempt precisely the measurement of the disorder in the sound frequencies that appear in the sonogram. The first method we have attempted is the natural candidate: Shannon’s entropy.

Shannon’s Entropy

A classical measure of disorder and uncertainty is Shannon’s entropy. Its goal is to obtain the disorder in the distribution of a signal. Thus, our initial proposal is to use Shannon’s entropy as a measure of the disorder of laughter.

Let X be a discrete random variable taking a finite number of possible values $x_1, x_2, \ldots, x_n$ with associated probabilities $p_1, p_2, \ldots, p_n$ respectively. Then

$$1 \geq p_i \geq 0 \quad i = 1,2,\ldots,n$$

$$\sum_{i=1}^{n} p_i = 1$$

Let h be a function defined on the interval (0,1) and $h(p)$ be interpreted as the uncertainty associated with the event $X = x_i$, $i = 1,2,\ldots,n$ or the information conveyed by revealing that X has taken on the value x_i in a given performance of the experiment. For each n, let be define a function H_n over the n variables $p_1, p_2, \ldots, p_n$. The function $H_n(p_1, p_2, \ldots, p_n)$ is going to be interpreted as the average uncertainty associated with the event $\{X = x_i\}$, $i = 1,2,\ldots,n$. Then

$$H_n(p_1, p_2, \ldots, p_n) = \sum_{i=1}^{n} p_i h(p_i) \tag{2.1}$$

To arrive to the exact expression of $H_n(p_1, p_2, \ldots, p_n)$ some axiomatic characterization is necessary:

H_n should be continuous in the p_i.

If all the p_i are equal, $p_i = \frac{1}{n}$, then H_n should be a monotonic increasing function of n.

If a choice is broken down into two successive choices, the original H_n should be weighted sum of the individual values of H_n.

Shannon showed [Shannon, 1948] than the only H_n satisfying the three above assumptions is of the form:

$$H_n(p_1, p_2, \ldots, p_n) = -k\sum_{i=1}^{n} p_i \log_a p_i \qquad (2.2)$$

where k is a positive constant, $a > 1$, and $0 \log_a 0 = 0$. The constant k plays a role of the election of a unit of measurement of the entropy. If $k = 1$ then the expression (2.2) is the Shannon's entropy.

The Entropy Content of Human Voice Versus Laughter

Let us focus first on the informational content of human voice. In Fig. 1 there is a sample of a sonogram of the five (Spanish) vowels: "a, e, i, o, u" from an adult male subject. The sonogram shows the perceived frequencies associated with the vibrational modes of the vocal chords. The characteristic vibration modes are subject to active amplification and resonances along the vocal tract so that the resulting sounds become highly distinguishable, as it is clear from the forms of the respective spectra. They are very different, and so it is very easy to distingue each vowel from the others. In the informational context described by Shannon, it seems that the vibration modes of the vocal cords are used to convey information, that is, human individuals use the form of the signal, in frequency domain, to send information.

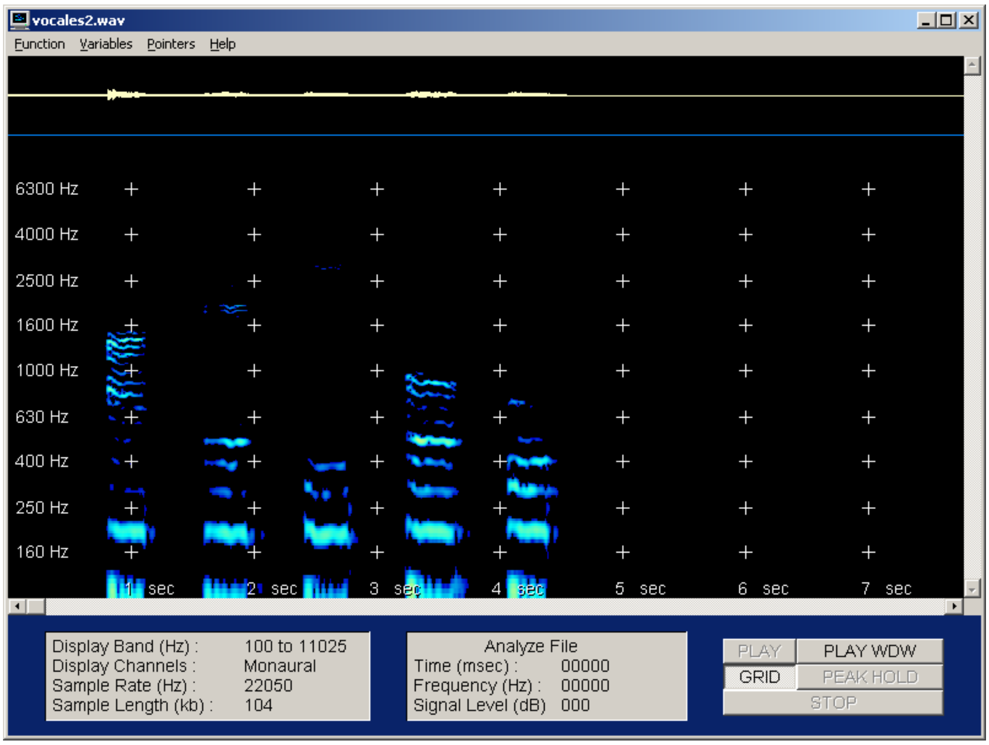
Fig. 2 shows a sonogram of a complete laughter episode. It is observed that there is not a predominance neither of any fundamental frequency nor of its multiples, except for very short periods of time. To measure the informational content of this laughter and its relationship with the above pieces of language, we are applying Shannon's entropy.

It is clear that there exists a discrete random variable X associated with this process. Obviously this random variable is discrete because the signal is discrete in time domain, so is discrete in frequency domain. The possible values $x_1, x_2, \ldots, x_n$ are the amplitude of each harmonic, with associated probabilities $p_1, p_2, \ldots, p_n$ respectively. The spectral density functions play for a random process $q(t)$ a role analogous to the Fourier analysis of a deterministic function, and describe the frequency content of the process. With reference to stationary processes, the power spectral density (PSD) is a real non-negative function defined as the Fourier transform of the auto-correlation function. To find the probabilities $p_1, p_2, \ldots, p_n$ associated with the random process $q(t)$ its necessary to normalize the PSD of the signal, to fulfill the condition $\sum_{i=1}^{n} p_i = 1$. The commands used to implement this algorithm were taken from MatLab. This procedure was applied to the entire laughter episode showed in Fig. 2, and to the “a” vowel, showed in Fig. 1. The results are shown in Table 1.

SIGNAL:	SHANNON’S ENTROPY:
Spanish “a” vowel	0.4104
Laughter	0.4127

Table l. Shannon’s entropy.

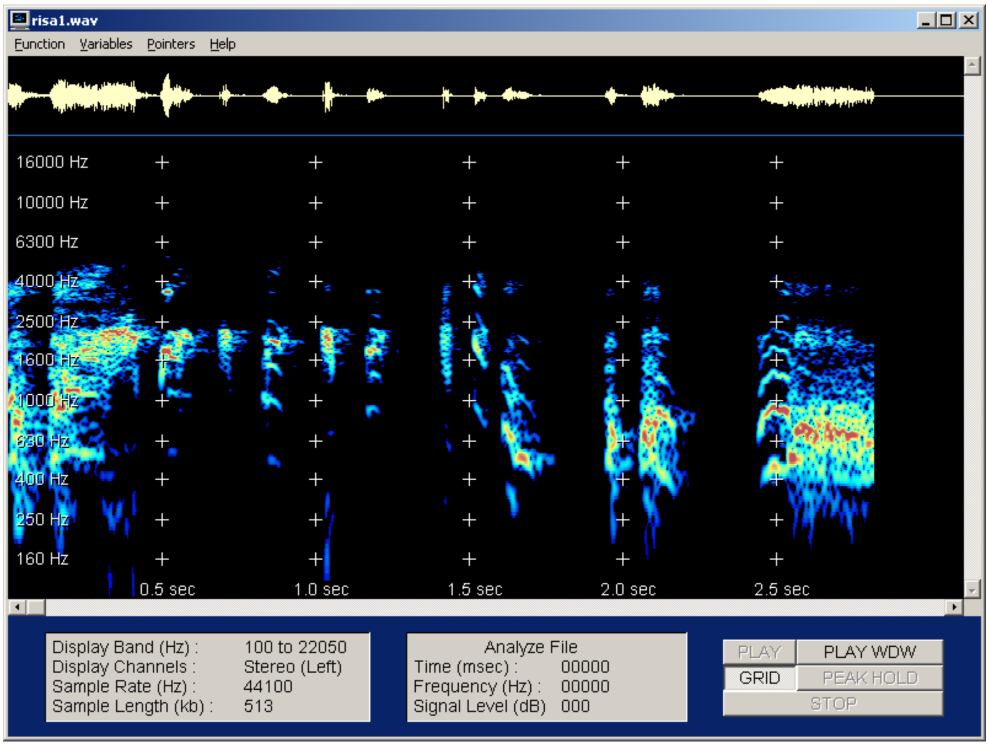
Surprisingly for the very different visual impression they convey, *Shannon’s entropy for both signals is quite similar*. Rather than the Shannon’s entropy, the Power Spectral Density (PSD) of both signals becomes far more significant. We show in Figures 3 and 4 the average PSD corresponding to a plosive of laughter in Fig. 2 and to the Spanish vowel *a* in Fig. 1. While the vowel *a* shows several of its characteristic ‘plateau’, *laughter appears very close to a power law distribution.*



Display Band (Hz) : 100 to 11025
Display Channels : Monaural
Sample Rate (Hz) : 22050
Sample Length (kb) : 104

Analyze File
Time (msec) : 00000
Frequency (Hz) : 00000
Signal Level (dB) 000

Figure 1. Sonogram of the five Spanish vowels, a-e-i-o-u; in English they correspond to the sounds: [ah], [eh], [ee], [oh], [oo].



Display Band (Hz) : 100 to 22050
Display Channels : Stereo (Left)
Sample Rate (Hz) : 44100
Sample Length (kb) : 513

Analyze File
Time (msec) : 00000
Frequency (Hz) : 00000
Signal Level (dB) 000

Figure 2. Sonogram of a laughter episode (a very intense and joyful one).

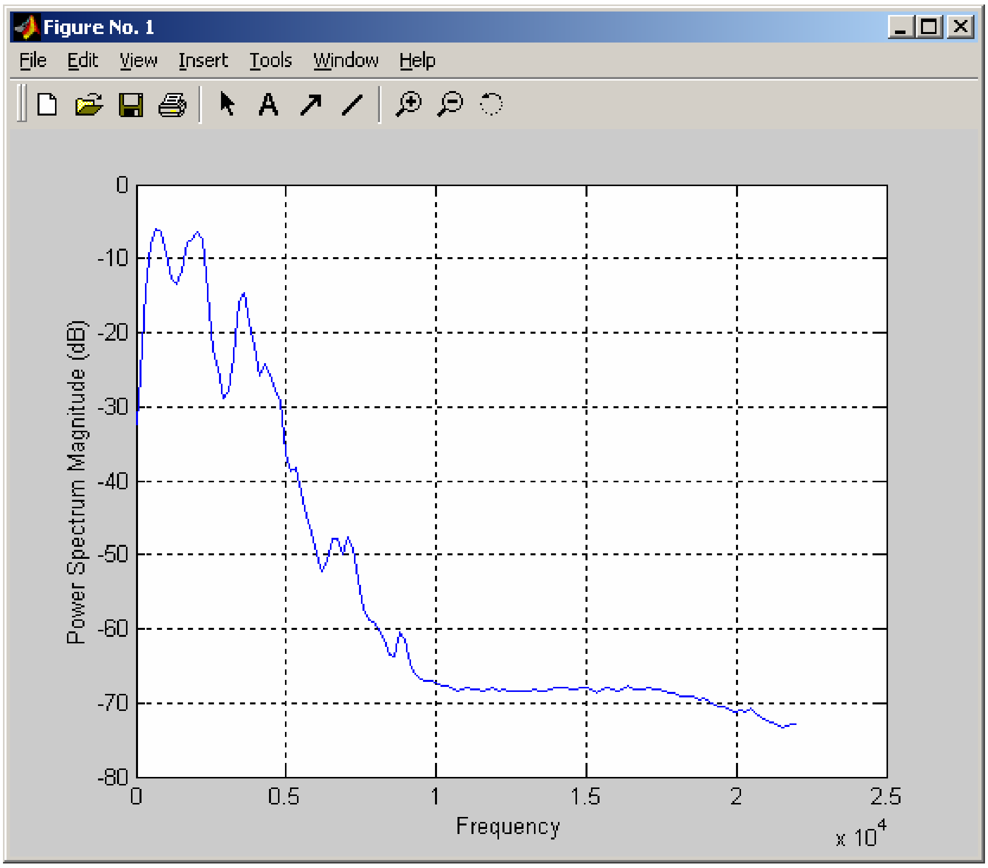


Figure 3. Power Spectral Density of a complete laughter episode, obtained from the signal showed in Fig. 2.

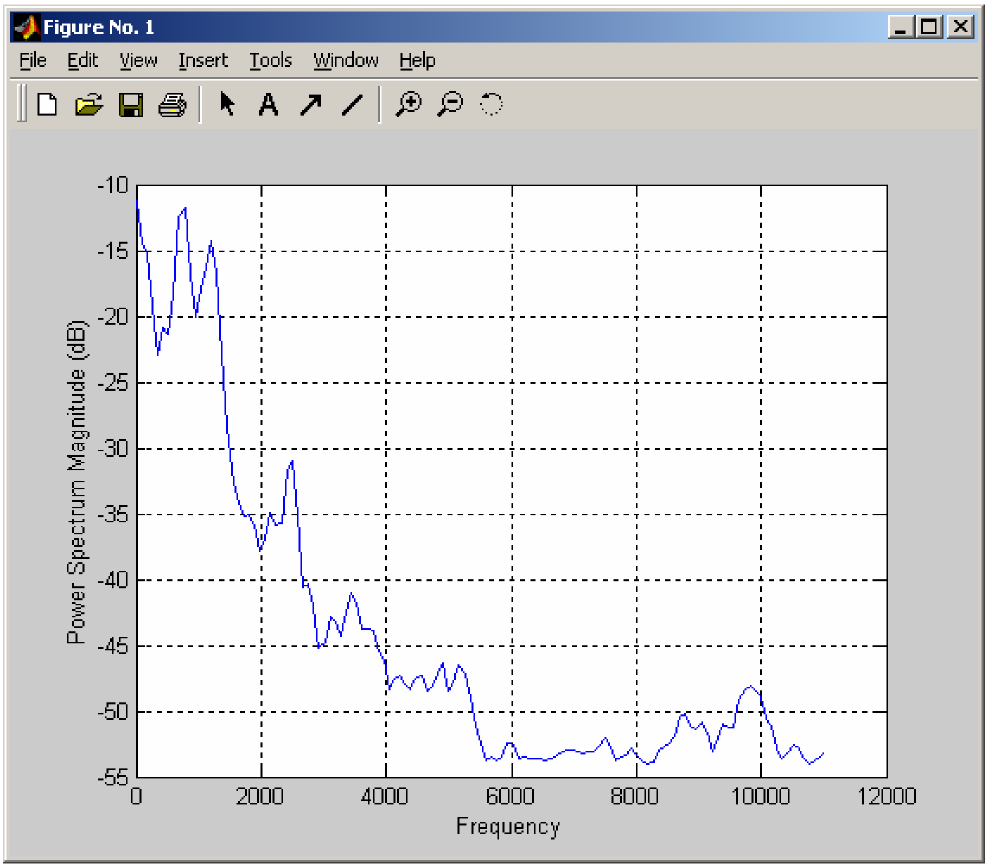


Figure 4. Power Spectral Density of a Spanish vowel ("a"), obtained from the first part of the signal showed in Fig. 1.

Closing Comments

Our analysis has barely begun. After Shannon's entropy and our brief PSD analysis, different wavelets and transforms related to the Fourier decomposition of signals will be explored by the authors. Our guiding hypothesis is that the mathematical form of laughter contains relevant cues in order to understand laughter's enigmatic behavioral and evolutionary roles. We also think that the dynamic process inherent of laughter may be very close to the dynamic processes in other sensory varieties (e.g., vision) and this opens the possibility of introducing powerful symmetry tools in the analysis, as has been done for instance by Michael Leyton in his treatment of forms [12]. Besides, the universality of laughter in human individuals (even in blind or deaf people) and its emergence in the most varied behavioral, cognitive and emotional contexts make this phenomenon one of the most interesting places to discuss candidate neurodynamic principles orienting human information processing, and the nature of emotions [4, 13, 14].

A brief comment about the surprising poor performance of Shannon's entropy may be in order. The informational context developed by Shannon was very different from the one considered here. He was focusing the attention on the number of bits necessaries to represent the information transferred. That is, he studied the number of bits necessaries in the code used (i.e. the Morse code), because this is the first step to study the entire information transfer between a source and a receptor, taking into account the noise introduced by the channel used. It is clear (and well known) from sonogram analysis, that human beings use the waveform in frequency domain to send and recognize phonemes. This process needs to obtain some particular vibrational modes of the vowel chords, with further amplification and resonance to establish some clear, highly characteristic plateaus. In the case of laughter it seems that there is simply an energy transfer from the expelled air to the vowel chords, no matter the resonance produced (and, apparently, the lack of active control leads to the power law signature we have mentioned). Perhaps this absence of any patterned signal is the best signature for a unique process: a minimization *de gratis* of looped neuronal excitations that had arisen in a context of relative surprise and have become behaviorally irrelevant (Marijuán, 2001b). The noisy public display of *'problem solved'* by socializing individuals has been precisely patterned upon the conspicuous absence of patterns (plosive's duration is highly irregular too).

In the context of unambiguously distinguishing, by formal tools, laughter from language, it seems necessary an ad hoc redefinition of the information-entropy conceptualization (which parts of the signal are really considered as signal?). The authors are investigating several ways to do this, some of them related to Javorszky's, Villarroel's and Marijuán's approach to biological communication [6]. Concerning the formal tools right now available to the authors, the next way might stem from the study of the frequency dispersion showed in the PSD: in fact, it is possible to define several measures of that dispersion. But the use of the wavelets seems highly adequate in order to characterize the disorder in frequency domain of laughter; actually wavelets are the best formal way to artificially generate and to recognize voice. In any case, they have to be supplemented by an intensity filter so as to get free of most of the irrelevant harmonics that accompany the vocal cord vibration (and which actually add considerable noise but very few information to the sound pattern).

It is our hope that, in future works, we will be able to precisely measure in how much spontaneous laughter distinguishes from the voluntary articulations of voice; by gaining further understanding on the 'form' of laughter we will contribute to illuminate its really intriguing neurodynamic nature and social role.

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