Series of similar vocal elements as a crucial acoustic structure in human laughter

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ABSTRACT

Among the many variable sounds in human laughter, vocalizations often contain series of vocal elements of similar acoustic properties. This study aims to elucidate whether such element series contain trajectories of changes in acoustic parameters that might be used to encode information, e.g. on the state of the signaller. We recorded bouts of laughter of adult humans (N = 17) and used a multi-parametric sound analysis to describe the acoustic parameters of vocal elements and their variation. We could show that these elements are distinguishable between individuals, but not necessary between female and male voices. We suggest that the series of similar elements with gradients in acoustic changes within laughter bouts might account for the stereotype and therefore predictable impression of laughter vocalizations.

Keywords: laughter vocalization, acoustic signaling, multi-parametric sound analysis.

ZUSAMMENFASSUNG

Innerhalb von Lachvokalisationen lassen sich Serien von Elementen mit ähnlichen akustischen Eigenschaften charakterisieren. Wir untersuchten, ob sich innerhalb solcher Elementfolgen Trajektorien akustischer Parameter-Änderungen beschreiben lassen, die zur Kodierung von Information genutzt werden können. Lachepisoden von 17 Erwachsenen wurden in einem multi-parametrischen Verfahren analysiert, um akustische Parameter von Elementen sowie deren Variabilität zu beschreiben. Die Elemente ließen sich anhand ihrer Eigenschaften den verschiedenen lachenden Personen zuordnen, das Geschlecht des Lachers war jedoch nicht in jedem Fall zu dekodieren. Wir schlagen vor, dass Serien ähnlicher Elemente mit geringen Veränderungen von Element zu Element sowie bestimmte Gradienten solcher Veränderungen den vorhersagbaren Höreindruck des Lachens hervorrufen.

1. INTRODUCTION

Some nonverbal human vocalizations such as infant crying or laughter contain series of acoustically similar elements [2,6,14]. It has been suggested that within such series, gradients of parameter changes might encode higher-order information that adds to the information encoded in the element structure [12]. Playback experiments using laughter recorded in natural settings or experimentally modified laughter did provide evidence that not only element characteristics, but also parameter changes within a series affect the evaluation of laughter by listeners [1,4,5,7,11].

The acoustic characteristics of human laughter have been investigated in several studies that either emphasized the stereotypy of the signal [8,9] or in contrary the enormous acoustic variability of laughter vocalizations [2,13]. Here, we investigate acoustic variation in laughter vocalizations by means of a multi-parametric sound analysis [10]. Comparing acoustic parameters of vocal elements for corresponding positions in a series will allow us to investigate the variability of laughter elements as well as rules underlying parameter changes within series of laughter elements.

2. METHODS

2.1. Recordings and acoustic analysis

We recorded spontaneous, unforced laughter during a reading task in which participants heard themselves with a short time delay (200 ms) through headphones (speech delayer: SPVZ, Geräte Zak, Simbach, Germany). This procedure led to problems in articulation which readily resulted in bursts of laughter (delay in playback was interrupted while recording laughter). 17 people volunteered to participate in the study (10 males, 7 females, mean age 36.6 ± 8.1 years). For recordings we used a DAT recorder (Sony TCD-

D10) connected to a Sennheiser ME 62 microphone.

Any laughter response that was comprised of a sequence of at least three elements was included in the analysis (overall, 178 bouts of laughter with 1515 elements). The acoustic properties of laughter vocalizations were analyzed using the sound analysis program Avisoft-SASLab Pro. R. Specht, Berlin (16-bit resolution, sampling rate 16 kHz). As a laughter *element*, we defined each discrete sound pattern that was not interrupted by pauses longer than 10 ms. Each *laughter bout* consisted of a number of elements within a wide range of acoustic characteristics and was finished either by a sound produced during inspiration or by the onset of speech. Laughter bouts often contained successions of similar elements. To operationally define these series, the following criteria was applied: *homotype element series* were all element successions where successive elements did not show more than 50 % difference in at least two of three acoustic parameters (duration, interval, and $F_{0\text{-max}}$, see Fig. 1 for illustration).

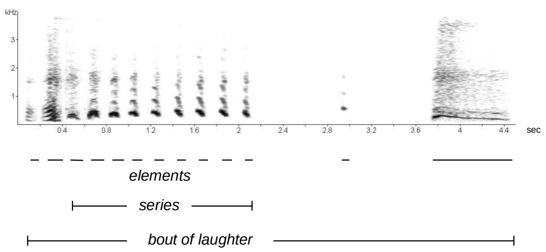

Figure 1: Spectrogram of a laughter vocalization (8 kHz, 16-bit). Acoustic structures are named below.

For each bout of laughter we measured the duration of the whole bout, of the series within the bout, and of each element, and for the latter, also the maximum value of the fundamental frequency. In addition, we obtained several measures for each element ('multi-parametric sound analysis') [10] by the following procedure: We digitized elements (8 kHz sample rate), and calculated spectrograms using a Fast Fourier Transformation (window size 512 sample points, overlap 93.75, time resolution 2 ms). Using the analysis program ConAn 0.9 (R. Mundry, Berlin), these spectrograms were used to calculate 115 measures on frequency and energy distribution over time and on the shape of the fundamental frequency for each element.

2.2. Data analysis and statistics

A discriminant function analysis (DFA) was applied to detect differences in laughter elements according to the two factors speaker identity and gender. In both analyses (speaker and gender), discriminant functions were calculated only on a subset of elements (internal elements, int.) whereas all elements were classified (external elements, ext., 'hold-out-sample method' [3]). Analyses were conducted with 7 acoustic parameters (statistic-based selection out of the 115 parameters measured), 14 subjects (7 male, 7 female), and 8 laughter series per subject. Loadings of parameters on the discriminant function were used to estimate their contribution to the discrimination of investigated classes.

All differences between groups or parameters were tested with non-parametric statistic tests.

To uncover trajectories of parameter changes within a laughter series, for some of the acoustic parameters measured, we calculated such changes according to the element's position within the series and introduced an additional measure (changes of 10 % or more) in order to roughly reflect perceptual abilities in humans. To assure comparability of results, this measure was only applied to series containing at least six elements.

3. RESULTS

3.1. Structure of laughter bouts

Laughter bouts were typically initiated by one or two 'singular' elements (i.e. non-repeated, with large variability in acoustic parameters). These were often followed by a succession of elements with predictable similarity, i.e. a homotype series. After this homotype series sometimes more singular elements followed and in the end often a sound produced during inspiration. Of all bouts analyzed, only 9 bouts (5%) produced by 7 different participants did not contain a homotype series. On the other hand, never did a bout of laughter contain more than one series.

In the majority of cases, homotype laughter series constituted the longest part of a laughter bout (Fig. 2). Same significant results were obtained by comparing the duration of temporal structures of the series for each participant, separately.

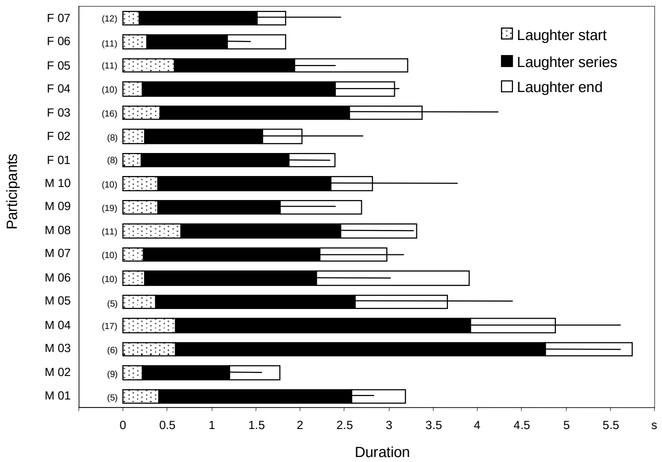

Figure 2: Temporal pattern of laughter bouts: series contribute most to a bout (Friedman one-way ANOVA for mean dur/subject, N=17, χ^2=34.0, p < 0.001).

Duration's of homotype laughter series did not differ between males and females, but we found considerable differences with respect to different participants.

3.2. Characterization of laughter elements in homotype series

The average rate of elements produced within series was 4.7 ± 0.8 /s. This measure did not differ between males and females, but between individuals, again. The results of the DFA also confirmed that individuality, but not gender, was distinguishable by the acoustic parameters of laughter elements (Table 1).

Table 1: Results of the discriminant function analyses and Binomial tests. Data were balanced by randomly selecting equal numbers (N=7) of subjects for genders. Within each analysis, subjects contributed equal numbers of internal elements.

	Subset	Correct classified (%)	Elements	*p*
Subject	int.	47.3	112	< .001
	ext.	19	807	< .001
Gender	int.	59	112	.01
	ext.	56	807	.07

Thus, laughter elements within series contained acoustic characteristics that, in their combination, made it possible to distinguish between laughing people. Parameters that were especially decisive for differences between subjects (i.e. such loading high on DF1) were those describing the frequency contour within an element: a measure of the fundamental frequency (FMedS), the slope of the element (as a measure of frequency contour, SlStEnd), the time until the minimal slope was reached (LocSlMin), and the maximal slope (SlMax).

3.3. Gradients of parameter changes within laughter series

For seven parameters (four that most effectively characterized individual differences and three that were efficient in eliciting different responses in playback experiments [4]), we correlated the measures of these parameters with the position of the elements in a series in order to describe gradients within acoustic parameters. We calculated Pearson's correlation coefficients for each parameter and each series, separately (all N=98, balanced for speaker and gender). Only the distribution of correlation coefficients for duration, interval, and fundamental frequency differed from a normal distribution, thereby pointing to gradients of parameter changes (Kolmogorov-Smirnoff-tests, duration: Z=1.47, p=0.03, interval: Z=2.60, p=0.001, fundamental frequency Z= 2.60, p=0.001, FMedS=1.37, p=0.05, SlStEnd, LocSlMin, SlMax: all Z<0.095, all p n.s.).

Correlation coefficients tended to be positive for intervals (22 positive out of 24 series with a significant correlation), whereas duration was clearly negatively correlated with element position (40 negative out of 46 series with a significant correlation). Element frequency within homotype series either decreased or increased (37 negative out of 48 significant correlation's). In other words: whereas intervals tended to get longer towards the end of a series, duration's declined in the course of a series. The fundamental frequency did show either decreasing or increasing gradients in different series.

The characterization of gradients by means of differences of at least 10 % between successive elements specified these results. Gradients showed a characteristic distribution over the course of the series (Fig. 3).

For the duration, increases did occur less often towards the end, whereas decreases tended to occur more often in the later transitions of a series. The interval was in most of the cases increasing within the course of a series. Pitch showed only few element transitions with differences of above 10 %. Increases of pitch occurred more often in the beginning of series, whereas decreases occurred more often towards the end of a series.

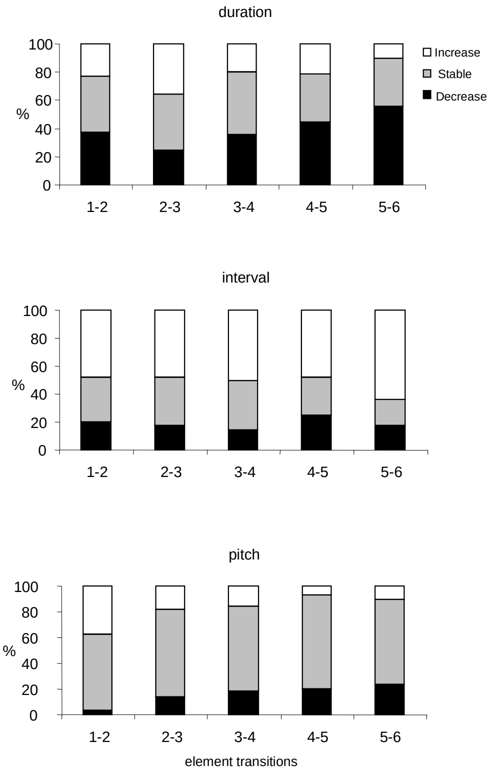

Figure 3: Proportion of gradients (increase, stable, decrease) in the element transitions of laughter by means of at-least-10-% differences between successive elements.

4. DISCUSSION

Inquiries into the structure of laughter elements and the dynamics of parameter changes in human laughter allowed us to show that this display includes sequences of similar vocal elements. Within such 'homotype series', acoustic parameters did only exhibit small changes from element to element. The comparison of acoustic features of successive elements uncovered some typical trajectories of parameter changes within laughter series. For example, there was a tendency for the duration of elements to decline within the series and for intervals to increase.

The range of parameter variability within the series of laughter elements is individually different, with measures characterizing the frequency shape of an element being especially decisive between subjects. Interestingly, neither these nor other investigated parameters showed systematic differences between female and male subjects. The failure to find such differences in our study might, on the one hand, be explained by methodological constraints. For example, whereas in other studies all laughter vocalizations performed during a whole bout or burst of laughter were analyzed, we considered only homotype laughter elements. On the other hand, listeners evaluating laughter sometimes did report difficulties to discriminate female and male voice characteristics (Kipper, unpublished data). Such a reduction of acoustic differences between male and female voices might point to the biological significance of laughter. There is a consensus that laughter is used as an 'in-group-signal' that serves to generate and maintain social bonds [e.g. 1,6,7]. A signal serving such a function might not be designed to accent differences between sub-groups.

We were able to extract specific rules of parameter variation within laughter series as given if parameter values shift from element to element within a sequence. Such rules, forming gradients or trajectories, have been documented in communicative systems of many animals and have been argued to serve communicative functions there [12].

5. CONCLUSION

In the present study we investigated the organization of laughter vocalizations applying the conceptual framework of homotype signal series. This allowed us to explain several features of human laughter and to extract rules of parameter variation. Studies on laughter vocalizations in different social settings are crucial to verify these results. At the same time such investigations will be the only way to raise our understanding on the signal design and variability of human laughter. These studies should include either side of the signaler/recipient system and consider the production and performance as well as the perception and evaluation of human laughter.

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