Journal of Nonverbal Behavior

Laugh like you mean it: Authenticity modulates acoustic, physiological and perceptual properties of laughter

--Manuscript Draft--

Manuscript Number:	JONB-D-14-00074R2
Full Title:	Laugh like you mean it: Authenticity modulates acoustic, physiological and perceptual properties of laughter
Article Type:	Original Research
Keywords:	Laughter, authenticity, phonation, acoustics, non-verbal emotional vocalizations, nasality
Corresponding Author:	Carolyn McGettigan Royal Holloway University of London Egham, UNITED KINGDOM
Corresponding Author Secondary Information:	
Corresponding Author's Institution:	Royal Holloway University of London
Corresponding Author's Secondary Institution:	
First Author:	Nadine Lavan
First Author Secondary Information:	
Order of Authors:	Nadine Lavan
	Sophie Kerrtu Scott
	Carolyn McGettigan
Order of Authors Secondary Information:	
Funding Information:	
Abstract:	Several authors have recently presented evidence for perceptual and neural distinctions between genuine and acted expressions of emotion. Here, we describe how differences in authenticity affect the acoustic and perceptual properties of laughter. In an acoustic analysis, we contrasted Spontaneous, authentic laughter with Volitional, fake laughter, finding that Spontaneous laughter was higher in pitch, longer in duration, and had different spectral characteristics from Volitional laughter that was produced under full voluntary control. In a behavioural experiment, listeners perceived Spontaneous and Volitional laughter as distinct in arousal, valence, and authenticity. Multiple regression analyses further revealed that acoustic measures could significantly predict these affective and authenticity judgements, with the notable exception of authenticity ratings for Spontaneous laughter. The combination of acoustic predictors differed according to the laughter type, where Volitional laughter ratings were uniquely predicted by harmonics-to-noise ratio (HNR). To better understand the role of HNR in terms of the physiological effects in vocal tract configuration as a function of authenticity during laughter production, we ran an additional experiment in which phonetically trained listeners rated each laugh for breathiness, nasality, and mouth opening. Volitional laughter was found to be significantly more nasal than Spontaneous laughter, and the item-wise physiological ratings also significantly predicted affective judgements obtained in the first experiment. Our findings suggest that as an alternative to traditional acoustic measures, ratings of phonatory and articulatory features can be useful descriptors of the acoustic qualities of non-verbal emotional vocalizations, and of their perceptual implications.

Royal Holloway
University of London
Egham, Surrey
TW20 0EX

Carolyn McGettigan

Royal Holloway Vocal Communication Laboratory

+44 (0)1784 44 3529

Carolyn.McGettigan@rhul.ac.uk

www.carolynmcgettigan.com

Professor Ursula Hess
Department of Psychology,
Humboldt University, Berlin
Rudower Chaussee 18, 12489 Berlin

6th June 2015

Dear Prof Hess,

Thank you for your email including the reviewers' comments on our manuscript "Laugh like you mean it: Authentic emotional experience modulates acoustic, physiological and perceptual properties of laughter".

We are delighted to hear that both you and the reviewers found our manuscript acceptable for publication in the Journal of Nonverbal Behaviour. We submit with this letter a revised version of the manuscript, having added the recent data mentioned by reviewer 1 (McKeown & Curran, 2015) and have corrected the reference list according to reviewer 2's comments.

Yours sincerely,

Carolyn McGettigan, Nadine Lavan, Sophie Scott

Laugh like you mean it: Authenticity modulates acoustic, physiological and perceptual properties of laughter

Nadine Lavan[1], Sophie K. Scott[2], Carolyn McGettigan[1,2]

[1]Department of Psychology, Royal Holloway, University of London, Egham, UK

[2]Institute of Cognitive Neuroscience, University College London, London, UK

Word count: 6045 (incl. abstract)

Correspondence to: Carolyn McGettigan, Department of Psychology, Royal Holloway, University of London, Egham Hill, Egham TW20 0EX, UK. Email: Carolyn.McGettigan@rhul.ac.uk. Phone: +44 (0) 1784 44 3529

Acknowledgements: We would like to thank Gary McKeown and one anonymous reviewer for thoughtful and constructive comments on earlier versions of the manuscript. Stimulus recording and data collection for Experiment 1 was supported by a Wellcome Trust Senior Research Fellowship (WT090961MA) awarded to Sophie Scott.

Abstract

Several authors have recently presented evidence for perceptual and neural distinctions between genuine and acted expressions of emotion. Here, we describe how differences in authenticity affect the acoustic and perceptual properties of laughter. In an acoustic analysis, we contrasted Spontaneous, authentic laughter with Volitional, fake laughter, finding that Spontaneous laughter was higher in pitch, longer in duration, and had different spectral characteristics from Volitional laughter that was produced under full voluntary control. In a behavioural experiment, listeners perceived Spontaneous and Volitional laughter as distinct in arousal, valence, and authenticity. Multiple regression analyses further revealed that acoustic measures could significantly predict these affective and authenticity judgements, with the notable exception of authenticity ratings for Spontaneous laughter. The combination of acoustic predictors differed according to the laughter type, where Volitional laughter ratings were uniquely predicted by harmonics-to-noise ratio (HNR). To better understand the role of HNR in terms of the physiological effects in vocal tract configuration as a function of authenticity during laughter production, we ran an additional experiment in which phonetically trained listeners rated each laugh for breathiness, nasality, and mouth opening. Volitional laughter was found to be significantly more nasal than Spontaneous laughter, and the item-wise physiological ratings also significantly predicted affective judgements obtained in the first experiment. Our findings suggest that as an alternative to traditional acoustic measures, ratings of phonatory and articulatory features can be useful descriptors of the acoustic qualities of non-verbal emotional vocalizations, and of their perceptual implications.

Keywords: Laughter, authenticity, phonation, acoustics, non-verbal vocalizations, nasality

1. Introduction

Laughter is ubiquitous in human communication: It is predominantly produced in conversation and during social interactions as a signal of agreement, liking, and social status (see Provine, 1993; Provine, 2001; Scott, 2013; Scott et al., 2014; see also Niedenthal et al., 2010 for smiles). Over and above such functional distinctions of laughter use, the laughter signal itself can be highly variable in its intensity, naturalness, degree of volitional control, emotional content, and authenticity, among other variables (see e.g. McKeown, Sneddon and Curran, 2014), and there is evidence that laughs differing in one or more or these parameters are distinct in their production mechanisms. For example, Ruch and Ekman (2001) suggest that the production mechanisms for Spontaneous and Volitional laughter differ fundamentally: Spontaneous laughter is considered to be inarticulate, with only minimal supralaryngeal modulations taking place and articulators being mostly in their resting positions, while this may not be the case for Volitional laughter. Wild, Rodden, Grodd, and Ruch (2003) offer a neurobiological elaboration of this argument, suggesting that distinct lateral versus midline neural systems may subserve the control of Volitional and Spontaneous laughter, respectively. Spontaneous laughter has thus been argued to include hard-to-fake acoustic features, marking it as a reliable, authentic signal for receivers, which is in contrast to Volitional laughter – an unreliable signal, potentially evolved to deceive receivers (e.g. Bryant and Aktipis, 2014; McKeown et al. 2014). Bryant and Aktipis (2014) consequently propose that due to an evolutionary arms race, humans have become experts both in producing fairly authentic sounding Volitional laughter as well as having a fine-tuned perceptual system to discriminate between the potentially well-matched Volitional and Spontaneous laughter – both skills that are beneficial for the individual.

Despite these apparent fundamental differences between Spontaneous and Volitional laughter, this distinction has received little attention in the emotion perception and production literature. A small number of studies has, however, recently addressed the issue of authenticity in emotional stimuli, some of them focusing on laughter. Bryant and Aktipis (2014) compared the acoustic properties of Volitional laughter to Spontaneous laughter, exploring pitch measures, duration measures, and an intensity measure. In this study, Spontaneous laughs were taken from conversations between friends, while Volitional laughs were taken from recordings from a separate group of individuals producing laughter voluntarily in a neutral emotional state. The authors collected behavioural categorisation judgements (labelling the stimuli as “real” or “fake”) from listeners, reporting above-chance categorisation accuracy. Using principal component analyses, the authors furthermore reported significant differences in a component including pitch measures – 0 fundamental frequency (F0) mean, standard deviation, minimum, maximum, and range all showed higher values for Spontaneous laughter. In another recent study, McGettigan, Walsh, Jessop and colleagues (2013) compared Volitional and Spontaneous laughter (labeled “Evoked” and “Emitted” in their study). Spontaneous signals were recorded from individuals watching amusing videos of their choice, while the Volitional laughter was produced by the same individuals under full control and without any external stimulation apart from the instruction to voluntarily produce natural-sounding laughter. The authors reported significant differences in pitch measures, with Spontaneous laughter having a significantly higher mean F0. Furthermore, differences in affective ratings of the laughs were found, where Spontaneous laughter was perceived as marginally more arousing and significantly more positively valenced.

Further evidence for differential processing of Spontaneous and Volitional vocalizations and speech can be found in studies exploring the neural underpinnings of authenticity perception in vocal emotions (Drolet, Schubotz and Fischer, 2012; 2013; 2014; McGettigan et al., 2015; Provine, 2012). Drolet and colleagues (2012; 2013; 2014) collected spoken accounts of emotional past events as told by interviewees on a radio contrasting them with a non-authentic condition created by actors who recreated the emotional speech verbatim. A problem with this approach is that the linguistically emotional content of the material was conflated with the prosodic cues to emotion. This problem is avoided when using non-verbal vocalizations – for example, McGettigan and colleagues (2015) investigated the perception of authenticity by measuring passive responses to their recordings of Volitional and Spontaneous laughter using functional MRI. All studies report distinct neural responses to Volitional versus Spontaneous stimuli, showing that authenticity of emotional stimuli can be detected both on a behavioural and neural level, thus challenging the assumption that these stereotyped and simulated images/sounds are processed in the same way as authentic vocal expressions.

The present study aims to explore the relationship between the acoustic properties and the perceived affective qualities of Spontaneous and Volitional laughter. Here, we define Spontaneous as laughter that was spontaneously produced in response to humorous videos, and Volitional laughter as natural-sounding laughter produced/acted under full voluntary control (see Gervais and Wilson, 2005; McGettigan et al., 2013). Previous studies have shown that perceptual judgements of Spontaneous and Volitional laughter differ, but there is, to date, no detailed account of how acoustic properties are linked to participants' judgements of the affective qualities of these kinds of laughter, nor whether subjective listener ratings can be predicted from these acoustic measures. While we acknowledge that the expression of laughter in everyday life cannot be simply boiled down to these two 'categories' (e.g. McKeown et al., 2014 ; Niedenthal et al., 2010), our aim was to generate two perceptually distinct laughter variants that could be used to form an initial investigation of these novel research questions. In a first experiment, we therefore performed an acoustic analysis exploring differences between Spontaneous and Volitional laughter, and combined this with a behavioral experiment that measured listeners' ratings of affective properties of the stimuli (arousal and valence). Based on the findings of Bryant and Aktipis (2014) and McGettigan and colleagues (2015), we predicted that Spontaneous laughter should be distinct in both its acoustic and affective properties from Volitional laughter. We furthermore predicted that distinct sets of acoustic measures would significantly predict perceptual ratings for Spontaneous and Volitional laughter (Sauter, Eisner, Calder and Scott, 2010). We also explored how variations in acoustic properties within the sets of Spontaneous and Volitional laughter affected affective ratings and judgements of perceived authenticity, as there is also evidence for differences in the acoustic make-up of different styles of laughter: Bachorowski and Owren (2001), distinguish between such different styles of Spontaneous laughter, based on their degree of voicing. They determined that the voicing has an impact on the perception of laughs: for instance, listeners considered more voiced laughs to be more positive, friendly and attractive.

Based on the findings of Experiment 1, we conducted a second experiment to collect ratings indexing physiological characteristics of laughter - nasality, mouth opening, and breathiness - using phonetically trained listeners. Studies have repeatedly found that traditional acoustic analyses using measures such as fundamental frequency, descriptors of spectral properties and duration measures are not sufficient to account for basic affective qualities, despite listeners being consistently able to perceptually judge properties such as the valence of a stimulus (Banse and Scherer, 1996). There is, however, evidence that broader measures of voice quality and other phonatory qualities play an important role in describing affective qualities of emotional stimuli (Gobl and Nì Chasaide, 2003). These features are not well captured by traditional acoustic measures, as changes in voice quality and phonation result in complex changes in a number of acoustic measures, thus making them difficult to identify in traditional acoustic analyses. By using phonetically trained listeners, as opposed to lay listeners, we were able to obtain relatively objective assessments of these features and could thereby identify alternative descriptors of the laughter. We predicted that Volitional and Spontaneous laughter would be significantly different from each other in perceived breathiness, nasality, and mouth opening.

2. Experiment 1

2.1 Materials

The stimuli were recorded with a Bruel and Kjaer 2231 Sound Level Meter fitted with a 4165 cartridge on a digital audio tape recorder (Sony 60ES; Sony UK Limited, Weybridge, UK) and fed to the S/PDIF digital input of a PC sound card (M-Audio Delta 66; M-Audio, Iver Heath, UK) with a sampling rate of 22.050 Hz in a sound-proof, anechoic chamber at University College London. The laughter was produced by 9 female speakers, none of whom was a professional actor. The speakers were seated at a distance of 30 cm at an angle of 15 degrees to the microphone and were asked to produce both genuine amusement laughter (Spontaneous) and voluntary, controlled laughter (Volitional). The laughter was recorded following the procedure used by McGettigan et al. (2013): for the Volitional laughs, speakers were instructed to produce laughter voluntarily and were recorded in isolation. Volitional stimuli were produced first, to avoid carry-over effects from the Spontaneous condition. To evoke this Spontaneous laughter, sound clips or videos chosen by the speakers were presented over a computer screen with the sound playing over headphones in the anechoic chamber. Individual laughs were extracted (Boersma and Weenink, 2010) and normalized for peak amplitude using PRAAT. Long episodes of laughter (> 6 seconds) were segmented into smaller units based on breathing patterns, and samples with a duration under one second were excluded. Due to a shortage of material in the case of Volitional laughter, two individual short samples were concatenated to form one longer bout (8 tokens in total).

Listeners in a pilot test (*N*=8) were presented with 480 stimuli (288 Spontaneous and 192 Volitional) via headphones and categorized each stimulus as ‘real’ and ‘posed’ using a button press. The aim of this pilot study was to select a final set of stimuli that reliably reflected clear differences in authenticity between the two sets of laughter, ensuring that the stimuli were representative exemplars of the intended emotion category (Sauter et al., 2010). A final set of stimuli was selected, that were categorized correctly by at least 7 out of 8 participants in the pilot study. One speaker was excluded at this point from further analysis as her Spontaneous laughs were not reliably categorized as such and did thus not meet the inclusion criteria. This resulted in a final set of 36 Spontaneous laughs (*mean frequency of "Real" labels* = 7.52/8, *SD* = .51) and 36 Volitional laughs (*mean frequency of "Posed" labels* = 7.77/8, *SD* = .42) including 4 laughter samples from each of the 8 remaining speakers.

2.2 Methods

2.2.1 Acoustic analysis

An acoustic analysis was conducted using PRAAT (Boersma and Weenink, 2010) to establish whether the Spontaneous and Volitional laughter differed significantly from each other in their acoustic features. The acoustic analysis included measures of fundamental frequency, spectral measures, measures of amplitude, thus covering a broad range of acoustic features that have been previously found to predict affective ratings and categorisation judgements for laughter (e.g Bachorowski, Smoski and Owren, 2001) and emotional vocalizations (Sauter et al., 2010; Scott, Young, Calder et al., 1997).

Total duration: Interval between the first zero-crossing of the onset to the final zero crossing after the offset of the laugh. Measures are given in seconds.

Burst duration: Bursts were defined as the vowel-like vocalic segments within each laugh. Burst duration was measured as the interval between the first zero-crossing of the onset to the final zero crossing of the offset of every (non-initial) burst, averaged across the number of bursts per laugh. Measures are given in seconds.

F0 mean: F0 mean in Hz was computed using the auto-correlation method in PRAAT. Pitch floor was set at 75 Hz and the pitch ceiling at 1000 Hz, due to laughs being high-pitched. The frame duration was selected automatically by the autocorrelation algorithm, resulting in a frame duration of .08 seconds.

F0 variability: Standard deviation of the F0 mean in Hz, divided by the total duration of the laugh.

F0 minimum and *F0 maximum*: F0 minimum and maximum are defined as the highest and lowest F0 measurement and were manually labelled to reduce the impact of doubling/halving errors on these measures.

F0 Range (Hz): F0 maximum - F0 minimum.

F0 Range (ST): F0 maximum - F0 minimum converted into semitones (formula: 12*log2(Hz)).

Percentage of Unvoiced Segments: Percentage of frames lacking harmonic structure.

Mean harmonics-to-noise ratio (HNR): Mean ratio of quasi-periodic to non-period signal across time segments.

Intensity: Mean intensity in dB relative to the auditory threshold - determined after the stimuli were normalized for peak amplitude.

Spectral centre of gravity: Measure for the mean height of the frequencies for each laugh, in Hz, which captures the weighting of energy in the sound across the frequency range.

These parameters were compared across Spontaneous and Volitional laughter sets using independent t-tests. The significance level was adjusted using Bonferroni correction for 12 comparisons (p = .004).

2.2.2 Affective ratings

19 participants ($Mean_{Age}$ = 29.7 years, *SD* = 1.7 years, 8 female) were recruited through the Psychology Subject Database of University College London. None of them reported any hearing impairments. The study was approved by the UCL Research Ethics Committee. Participants were tested in individual sessions lasting around 70 minutes and were paid £10 for their time. The stimuli were presented to the participants over AKG K450 headphones on a laptop computer in randomized order using the Cogent2000 toolbox (www.vislab.ucl.ac.uk, version 1.29) and MATLAB (version R2010a 7.1.0, MathWorks, Natick, MA). Participants were asked to rate valence *("How positive or negative is this laugh?")* and arousal *("How exciting and intense is this laugh?")* of the stimuli on a 1-7 Likert scale. The valence scale ranged from 1 meaning "very negative" and 7 "very positive", with 4 representing neutral valence. The unipolar arousal scale ranged from 1 meaning "not exciting or intense at all" to 7 "very exciting and intense". The order of the rating tasks was randomized and all tasks were self-timed. Participants were unaware of the presence of Volitional and Spontaneous laughs during the affective rating tasks. After these tasks, participants were told about the presence

of Volitional and Spontaneous laughter and were asked to make a forced-choice authenticity judgement on each laughter sample, categorizing the laughs as '*real*' (defined as laughter that is produced in response to a strong positive state) or '*posed*' (defined as an acted display of laughter). For each laugh, the average frequency of '*real*' categorizations across the group was computed, generating a proportion score that described the likelihood of each laugh being categorized as Spontaneous – thus, an average score of 1 would indicate that the laugh was always judged as '*real*' and 0 that it was always judged as '*posed*'.

2.2.3 Multiple regressions

To explore whether the acoustic characteristics of laughter can predict the participants' affective judgements within and across laughter sets, separate multiple regression analyses were conducted for arousal, valence and authenticity measures as response variables (e.g. Laukka, Juslin, and 2005); Sauter et al., 2010). Separate models were created for 1) all laughs, 2) Spontaneous laughter, and 3) Volitional laughter, in order to explore effects across all the samples and within the two pre-defined categories. The predictors were the trial-specific measurements obtained in the acoustic analysis[1], and the response variables were the item-wise average ratings obtained from the affective rating tasks (arousal and valence) and the proportion of "*real*" labels in the authenticity task.

2.3 Results

2.3.1 Acoustic analysis

Table 1 displays the descriptive statistics and the results of independent t-tests comparing the acoustic properties of Spontaneous and Volitional laughter. There were significant differences between Volitional and Spontaneous laughter for most of the measured acoustic parameters.

[1] To avoid multicollinearity being present in the dataset, only F0 mean, F0 variability, total duration, burst duration, percentage of unvoiced segments, harmonics-to-noise ratio, spectral center of gravity and intensity were used in the regression.

Spontaneous laughter had a longer total duration, shorter burst duration, higher F0 mean, higher F0 minimum and maximum, a larger F0 variability, a higher percentage of unvoiced segments and lower mean intensity (all *p*s $\leq$ .001). The remaining comparisons revealed marginal or non-significant differences (F0 range [Hz], p = .006; HNR p = .391; F0 range [ST], p = .615, and spectral centre of gravity, p = .019).

INSERT TABLE 1 HERE

2.3.2 Affective ratings and authenticity

Independent t-tests showed significant differences between Volitional and Spontaneous laughter for arousal and valence (all *p*s $\leq$ .001). Volitional laughter was perceived to be lower in arousal and less positive than Spontaneous laughter. The results are shown in Table 2. The two groups furthermore differed significantly in their perceived authenticity ($p < .001$), where the Spontaneous laughs were perceived as more genuine. For 68.9% of presentations, Spontaneous laughter tokens were labelled as "*real*", while Volitional tokens were judged as being "*real*" in only 25.4% of all presentations (i.e. they were correctly categorised in 74.6% of all trials). We note here that this mean difference in perceived authenticity was expected, as our Spontaneous and Volitional laughter samples had been pre-selected using pilot categorization data. The primary motivation for obtaining these judgements and deriving the item-wise authenticity scores was so that we could explore the acoustic predictors of the perceived affective qualities of the laughter samples, both within and across the Spontaneous and Volitional sets. Notably, arousal, valence and autehenticity were highly inter-correlated for both Spontaneous and Volitional laughter (Pearson's r = .596 - .777 for Spontaneous laughs and .587 - .715 for Volitional laughs; all *p*s < 0.001).

INSERT TABLE 2 HERE

2.3.4 Multiple regressions

All regression models were significant, with the exception of the model predicting the perceived authenticity of Spontaneous laughter. The predictors explained between 60% and 79% of the variance when all laughs were entered into the model as one group, between 8% and 68% for Spontaneous laughter and between 35% and 67% for Volitional laughter (see Table 3 for the full results). Since arousal, valence, and authenticity were highly inter-correlated when considering all laughs as a single group (all *p*s < .001), these models exhibited similar sets of acoustic predictors, where total duration, F0 mean, HNR, spectral centre of gravity and burst duration (in the case of authenticity) significantly predicted affective properties. When Spontaneous and Volitional laughs were analysed separately, total duration, F0 mean, and spectral centre of gravity predicted ratings for Spontaneous laughs, while total duration, spectral centre of gravity, and HNR predicted ratings for Volitional laughs. Notably, the significant predictors differed for Spontaneous and Volitional laughter: HNR predicted perceived arousal, valence and authenticity for Volitional laughs (while spectral centre of gravity and total duration were additional predictions of arousal ratings), whereas HNR did not predict any of the affective properties of Spontaneous laughter (Table 3).

INSERT TABLE 3 HERE

2.4 Discussion

2.4.1 Acoustic analysis

We found significant acoustic differences between Volitional and Spontaneous laughter, which is in line with previous studies (e.g. Bachorowski et al., 2001; Bryant and Aktipis, 2014; McGettigan et al., 2015; Vettin and Todt, 2004). Higher values for all F0 measures in the Spontaneous laughter compared to Volitional laughter were found, confirming Bryant and Aktipis' (2014) and McGettigan and colleagues' (2015) findings. Further, Spontaneous laughter had fewer voiced segments and shorter bursts than Volitional laughter. Spontaneous laughter, produced involuntarily in response external stimulus, is characterized by an initial noisy forced exhalation (Ruch and Ekman, 2001), expelling most of the air in the lungs and thereby making sustained phonation increasingly difficult. This then results in a decline of amplitude and duration in laugh bursts (Ruch and Ekman, 2001; Provine and Yong, 1991). In line with this characterization of intense laughter, we found a significantly lower mean intensity (dB) for Spontaneous laughter compared to Volitional laughter: due to the more dynamic and variable intensity profile for Spontaneous laughs, peak amplitude normalization resulted in a lower average intensity for these laughs. These results show that the differences in the production mechanisms introduced by different levels of authenticity have a major impact on the acoustic features of laughter, leading to distinct signals.

2.4.2 Perceptual ratings

The results of the behavioural study confirm that Spontaneous and Volitional laughter are perceived as being different in arousal, valence, and authenticity. This supports findings that participants are able to accurately identify and categorise Volitional and Spontaneous laughter (Bryant and Aktipis, 2014; McGettigan et al., 2015) and that differences in the authenticity of laughter during the production of laughter can shape the perception of its affective qualities (McGettigan et al., 2015). Correlations between arousal and authenticity indicate that these measures are intimately linked. A similar finding has been reported by McKeown and Curran (2015), showing that laughter intensity and humour (perceived amusement of the laugher) are highly correlated. McKeown and colleagues (2014) note that increasing laughter intensity (a concept similar to arousal in this study) seems to be closely linked to the presence of “hard-to-fake” properties of vocalisations such as laughter, thus marking reliable signals of authenticity. They furthermore argue that laughter that is lower in intensity seems to be easier to fake, which is in line with these high correlations. Therefore, while clear distinctions between arousal, valence, and authenticity were found, similar patterns of correlations between affective rating scales and authenticity within and across groups may also be an indicator that clear-cut category distinctions are overly simplistic: laughter categories may not exists and perceptual differences may be more continuous in nature based on interacting changes between perceptual features.

2.4.3 Multiple regressions

The relationship between acoustic features and affective ratings, such as arousal and valence, has not previously been established for a contrast of authenticity in emotional vocalizations. Our multiple regression analyses showed that judgements of arousal, valence and authenticity for Spontaneous and Volitional laughter can be predicted from sets of acoustic parameters with the exception of authenticity judgements for Spontaneous laughter. For the significant regression models, the sets of significant predictors were similar across all response variables, due to high inter-correlations between the arousal, valence and authenticity scores: longer total duration, higher F0, higher spectral centre of gravity and lower HNR (and shorter burst duration in the case of authenticity) predicted ratings on all of the affective scales when all the laughs were combined into a single group. Changes in F0 measures and more energy in the higher frequencies (higher spectral center of gravity) has been linked to the physiological changes associated with increased arousal, such as faster respiration, increased cardiovascular activity and increased muscle tension (Johnstone, Scherer, and Klasmeyer, 2003; cf. Juslin and Laukka, 2003 for emotional speech; Sauter et al., 2010 for emotional vocalizations). To date, the acoustic correlates of valence are not well defined, with studies struggling to find significant predictors of valence ratings for vocal emotions (Juslin and Laukka, 2003 for emotional speech; Sauter et al., 2010 for emotional vocalizations). In the current study, we included only positively valenced laughter sounds, which may explain the high correlation of valence with the other scales, as well as the relatively larger proportion of variance accounted for by the regression models compared with previous studies.

Crucially, consistent differences emerged in terms of the acoustic predictors of ratings for Spontaneous and Volitional laughter. For ratings of Spontaneous laughs, combinations of total duration, spectral center of gravity and F0 mean were the predominant predictors. In contrast to this, HNR was the most frequent predictor for affective ratings of Volitional laughs, predicting ratings in this group. An inspection of the data revealed a highly significant negative correlation of HNR with the authenticity scores and ratings for Volitional laughter, while positive or non-significant correlations are apparent for Spontaneous laughs (Figure 1).

INSERT FIGURE 1 HERE

Volitional laughs with a lower HNR were thus perceived as being more authentic, more positively valenced, and higher in arousal. HNR is an acoustic feature that is modulated by various factors, such as vocal qualities, types of phonation and other articulatory features (e.g. Eskenazi, Childers, and Hicks, 1990). A lower HNR has been used as a measure of vocal aging (Ferrand, 2002), to describe hoarse, rough, and breathy voices (Eskenazi, Childers, and Hicks, 1990; de Krom, 1995), and as an indicator of voice disorders (Parsa and Jamieson, 2001). A high HNR has been associated with increased "vocal clarity" (e.g. Warhurst, Madill, McCabe et al., 2012). Notably, all these descriptions of the impact of changes in HNR on the voice refer to changes in overall voice quality.

Strikingly, traditional acoustic measures could not predict a significant amount of variance for authenticity scores in Spontaneous laughter. This is unlikely to have occurred due to a narrow range of authenticity scores for Spontaneous laughter, as both the range of scores as well as the standard deviation exceeds that of Volitional laughter, for which we obtained a significant model ($Range_{Spontaneous}$: .11 - .89, $Range_{Volitional}$: .05 - .68; $SD_{Spontaneous}$ = .2, $SD_{Volitional}$ = .17). The lack of significant acoustic predictor may instead relate to the non-linearities in the acoustic signal that result from the physiological effects during intense Spontaneous laughter and are not easily captured by averaged acoustic measures.

It has, however, been shown that measures mapping articulatory and phonatory features during production, such as voice quality, may provide additional meaningful descriptors of these signals (Gobl and Nì Chasaide, 2003; Scherer, 1986). To further explore whether indexes of physiological features, such as phonatory and articulatory qualities could shed further light on systematic differences between Volitional and Spontaneous laughter, we ran a second study, collecting ratings of perceived breathiness, nasality and mouth opening from trained listeners.

3. Experiment 2

3.1 Materials

The stimuli were identical to those used in Experiment 1.

3.2 Methods

Ten phonetically trained listeners aged between 25 and 36 years (7 female; M_{age} = 27.3 years) were tested in individual sessions lasting around 45 minutes, and were paid £6 for their time. Each individual had extensive training in phonetics at university level as part of postgraduate degree courses in speech and language therapy, linguistics, and phonetics. Ethical approval for this study was obtained from the Departmental Ethics Committee at the Department of Psychology, Royal Holloway, University of London. Based on the associations of a breathy and rough voice quality with a low HNR (e.g. de Krom, 1995; Eskenazi, Childers, and Hicks, 1990), we collected ratings of breathiness for all laughs. Studies on laughter have occasionally reported the presence of voiced, nasalized as well as closed mouthed laughter (Kohler, 2008; Ruch and Ekman, 2001) associating it with “mild”, low-arousal laughter (Ruch and Ekman, 2001) - an articulatory feature that was also observed in the current stimulus set. We therefore additionally collected ratings of the degree of nasality and mouth opening for the stimuli.

The procedure was similar to the one described in Experiment 1. Participants were presented with the stimuli, rating each stimulus for its perceived breathiness, mouth opening[2] and nasality on a scale from 1 (not at all) to 7 (very). Stimuli and scales were presented in randomized order via

[2] Only 4 trained listeners completed the mouth opening scale.

headphones on a laptop computer running MATLAB (Version 2013b; Mathworks, Inc., Natick, MA) and the Psychophysics Toolbox extension (http://psychtoolbox.org/). Ratings were made using a key press. We predicted that Volitional laughter would be significantly different in nasality, degree of mouth opening and breathiness from Spontaneous laughter. We also expected that these measures would successfully predict the affective ratings and authenticity judgements collected in Experiment 1.

3.3 Results

HNR was negatively correlated with breathiness (Pearson's $r = -.404$, $p = .015$) and mouth opening (Pearson's r = -.434, p = .008) and positively correlated with nasality (Pearson's $r = .311$, $p = .065$) for Volitional laughter, but not for Spontaneous laughter (breathiness: Pearson's $r = .103$, $p = .549$; nasality: Pearson's $r = -.2$, $p = .242$, mouth opening: Pearson's $r = .026$, $p = .882$). T-tests showed that Volitional laughter is significantly more nasal ($t[2,70]=-3.248$, $p = .002$), while there was no significant difference between laughter groups for breathiness ($t[2,70]=-.762$, $p = .449$) and mouth opening ($t[2,70]=1.601$, $p = .114$).

Multiple regression analyses were performed including nasality, mouth opening, and breathiness as predictors for regression models including models for 1) all laughs, 2) Spontaneous laughter and 3) Volitional laughter. All regressions models were significant, with the exception of those predicting arousal for Spontaneous laughter and authenticity for Volitional laughter (both ps < 0.08). The variance accounted for by the physiological measures across all regression models ranged from 13% to 36%. Breathiness and mouth opening were the predominant predictors for ratings within Spontaneous laughs and all laughs, while predictors were more varied for Volitional laughter (see Table 4).

As the ratings of physiological properties used here reflect, to some extent, complex changes in acoustic properties, additional hierarchical multiple regression analyses were performed to assess if physiological ratings can independently and over and above the variance explained by acoustic measures account for additional variance in perceived affective qualities. All acoustic measures were entered as a first block of predictors, while nasality, mouth opening, and breathiness were entered as a second block of predictors. The R^2 change for the phonatory/articulatory predictors of authenticity in Spontaneous laughter, over and above the contribution of the acoustic predictors, was marginally significant ($F = 2.713$, $p = 0.067$); all other R^2 changes were non-significant.

INSERT TABLE 4 HERE

3.4 Discussion

This experiment illustrates systematic differences in levels of nasality between Volitional and Spontaneous laughter and shows a link between HNR, physiological ratings, and affective qualities for the two laughter sets. Changes in physiological features introduce complex modulations to measures used in traditional acoustic analyses. We nonetheless found an association between HNR and the three physiological scales of nasality, mouth opening, and breathiness for Volitional laughter - increased HNR was related to lower levels of breathiness, a more closed mouth, and higher levels of nasality. It is unclear why this correlation is limited to Volitional laughter only. While there truly may be no association for Spontaneous laughter, another explanation may be difficulties in extracting HNR from the Spontaneous sounds. HNR is only measured for the clearly periodic sections in the signal: Spontaneous laughter is a dynamic signal that frequently incorporates non-linear acoustic features such as turbulent and noisy breathing and wheezing, alternating and at times overlapping with clearly voiced bursts. During such bursts, the periodic signal may be distorted by non-linear features, possibly resulting at times in unreliable detection of the presence of voicing by the analysis software (Praat; Boersma and Weenink, 2010). Such cases could possibly bias HNR measurements for Spontaneous laughter towards higher values by not accounting for these segments of the signal (relative to Volitional laughter, where non-linearities occur less frequently).

Volitional laughter was found to be significantly more nasal than Spontaneous laughter. Nasalised laughter has been described previously (Bachorowski et al., 2001; Edmonson, 1987; Habermann, 1955), and has usually been associated with low arousal states (Ruch and Ekman, 2001), which is reflected in the current study in lower perceived arousal ratings for Volitional laughter. Nasality is the result of a lowered velum, allowing air to travel through the nasal cavity as opposed to the oral-only airflow when the velum is raised. During phonation, the velum is habitually raised, making a lowered velum a marked feature. Similar to nasality, the degree of mouth opening has been attributed to laughter that is low in arousal: intense authentic laughter is accompanied by an opening of the mouth (Ruch and Ekman, 2001) as the facial expression occurring during such laughter is thought to have evolved from the 'play face' display (e.g. Darwin, 1872; Van Hooff, 1972). The presence of nasality - that is, a lowered velum and a less open mouth - in Volitional laughter may therefore indicate increased voluntary control in the production of this laughter, allowing for a wider variety of supralaryngeal modulators to take place during production.

The physiological ratings explained a significant amount of variance for arousal, valence, and authenticity across all laughs, for arousal and valence for Volitional laughter, and for valence and authenticity for Spontaneous laughter. This shows that physiological features can be useful alternative descriptors of the affective qualities of non-verbal emotional vocalizations, and their perceptual implications, and can provide additional information to traditional acoustic analyses (most notably in the prediction of authenticity ratings for Spontaneous laughter, which could not be predicted using traditional acoustic measures alone).

4. General discussion

The current study suggests that the degree of authenticity of laughter has an impact on its production mechanisms. These differences in production result in physiological changes that are conveyed in acoustic changes to the signal, providing meaningful cues for listeners' perception of affective qualities such as arousal, valence, and degree of authenticity of the vocalization. We have presented evidence that Spontaneous and Volitional laughter differ in their acoustic, physiological, and affective properties, confirming the findings of previous research (Bryant and Aktipis, 2014; McGettigan et al., 2015). We furthermore demonstrate that acoustic as well as physiological measures can successfully predict ratings of arousal, valence, and authenticity judgements for Spontaneous and Volitional laughter, with distinct sets of predictors emerging for the individual groups.

While acoustic measures, such as F0 mean, spectral centre of gravity, HNR and total duration among others are able to account for a large proportion of the variance in ratings of arousal, valence and authenticity within and across Spontaneous and Volitional laughter, the physiological measures, nasality, degree of mouth opening, and breathiness also explained a significant amount of variance. Strikingly, in the case of Spontaneous laughter, physiological measures explained more of the variance than acoustic measures in authenticity judgements in the simple regression models. Hierarchical multiple regression analyses revealed that physiological measures can account for marginally significantly more of the variance than the acoustic parameters ($p = 0.067$). Thus, using alternative descriptors such as phonatory and articulatory ratings may yield a more comprehensive description of nuanced (within category) differences in vocal emotions.

In the current study, we used expert listeners to collect ratings of physiological features, such as nasality, working as proxies for direct measures of movements of the vocal tract during the production of authentic vocalisations. It is crucial to consider laughter as a motor act: therefore, future work should aim to directly investigate the effects of authenticity and volitional control on the shaping of the vocal tract and articulator positioning. Techniques such as real-time MRI allow for *in vivo* measurements of the entire vocal tract during vocalization (e.g. Narayanan, Nayak, Lee, and Byrd, 2004) - this would, for example, allow for a direct examination of candidate articulatory markers of lower arousal in volitional laughter, such as velum lowering leading to increases in nasal airflow.

Our study focused on exploring the relationship of acoustic and perceptual properties in only two sets of laughter: Spontaneous, high-intensity laughter compared to Volitional, low-intensity laughter. Research has, however, shown that laughter is a highly complex signal with many overlapping functions. It has also been questioned whether distinct types of laughter proposed in the literature are reflected in reality or whether laughter varies along continua, with no clear-cut category boundaries – for example, high-intensity laughter produced during tickling or humour, may be perceived as categorically distinct from lower-intensity laughs produced during social interactions, yet all of these examples can be described as spontaneous to varying degrees (McKeown et al., 2014). Such complexities should be considered and empirically addressed in future work to assess how notions of authenticity, arousal, emotionality and social context among others shape and interact with the production and perception of laughter.

References

Bachorowski, J. A., & Owren, M. J. (2001). Not all laughs are alike: Voiced but not unvoiced laughter readily elicits positive affect. *Psychological Science*, *12*(3), 252-257.

Bachorowski, J.-A., Smoski, M.J., and Owren, M.J. (2001). The acoustic features of human laughter. *Journal of the Acoustical Society of America* 110, 1581–1597.

Banse, R., and Scherer, K. R. (1996). Acoustic profiles in vocal emotion expression. *Journal of Personality and Social Psychology* 70(3), 614–636.

Boersma, P., and Weenink, D. (2010). *Praat: doing phonetics by computer* [Computer program]. Version 5.1.13.

Bryant, G. A., and Aktipis, C. (2014). The animal nature of spontaneous human laughter. *Evolution and Human Behavior* 35, 327–335.

Darwin, C. (1872). *The expression of the emotions in man and animals*. London: Murray.

de Krom, G. (1995). Some spectral correlates of pathological breathy and rough voice quality for different types of vowel fragments. *Journal of Speech and Hearing Research*, 38, 794–811.

Edmonson, M.S. (1987). Notes on laughter. *Anthropological Linguistics* 29 (1), 23-34.

Eskenazi, L., Childers, D. G., and Hicks, D. M. (1990). Acoustic correlates of vocal quality. *Journal of Speech and Hearing Research*, *33*, 298–306.

Gervais, M., and Wilson, D. S. (2005). The evolution and functions of laughter and humor: A synthetic approach. *Quarterly Review of Biology* 80, 395–451.

Habermann, G. (1955). *Physiologie und Phonetik des lauthaften Lachens*. Leipzig: J. A. Barth.

Juslin, P., and Laukka, P. (2003). Communication of emotions in vocal expression and music performance: Different channels, same code?. *Psychological Bulletin* 129, 770–814.

Kohler, K. J. (2008). “Speech – Smile”, “Speech – Laugh”, “Laughter” and their sequencing in dialogic interaction. *Phonetica* 65, 1–18.

Laukka, P., Juslin, P., and Bresin, R. (2005). A dimensional approach to vocal expression of emotion. *Cognition and Emotion* 19, 633-653.

McGettigan, C., Walsh, E., Jessop, R., Agnew, Z. K., Sauter, D. A., Warren, J. E., and Scott, S. K. (2015). Individual Differences in Laughter Perception Reveal Roles for Mentalizing and Sensorimotor Systems in the Evaluation of Emotional Authenticity. *Cerebral Cortex*, 25 (1): 246-257.

McKeown, G., & Curran, W. (2015). The Relationship Between Laughter Intensity and Perceived Humour (pp. 27-29). Proceedings of the The 4th Interdisciplinary Workshop on Laughter and other Non-Verbal Vocalisations in Speech, Enschede, Netherlands.

McKeown, G., Sneddon, I., & Curran, W. (2015). Gender differences in the perceptions of genuine and simulated laughter and amused facial expressions. *Emotion Review*, *7*(1), 30-38.

Narayanan, S., Nayak, K., Lee, S.B., and Byrd, D. (2004). An approach to real-time magnetic resonance imaging for speech production. Journal of the Acoustical Society of America 115, 1771-1776.)

Niedenthal, P. M., Mermillod, M., Maringer, M., & Hess, U. (2010). The Simulation of Smiles (SIMS) model: Embodied simulation and the meaning of facial expression. *Behavioral and brain sciences*, *33*(06), 417-433.

Provine, R. R. (1993). Laughter punctuates speech: Linguistic, social and gender contexts of laughter. *Ethology*, *95*(4), 291-298.

Provine, R. R. (2001). *Laughter: A scientific investigation*. New York: Penguin.

Provine, R. R. (2012). *Curious behavior: Yawning, laughing, hiccupping, and beyond*. Cambridge: Harvard University Press.

Provine, R. R., & Yong, Y. L. (1991). Laughter: A stereotyped human vocalization. *Ethology*, *89*(2), 115-124.

Ruch, W., and Ekman, P. (2001). “The expressive pattern of laughter,” in *Emotion, qualia, and consciousness*, ed. A.W. Kaszniak (Tokyo: Word Scientific Publisher), 426-443.

Sauter, D., Eisner, F., Calder, A. J., and Scott, S. K. (2010). Perceptual cues in nonverbal vocal expressions of emotion. *Quarterly Journal of Experimental Psychology* 63(11), 2251–2272.

Scott, S. (2013). Laughter-the ordinary and the extraordinary. *Psychologist*, *26*(4), 264-268.

Scott, S. K., Lavan, N., Chen, S., & McGettigan, C. (2014). The social life of laughter. *Trends in cognitive sciences*, *18*(12), 618-620.

Scott, S. K., Young, A. W., Calder, A. J., Hellawell, D. J., Aggleton, J. P., and Johnson, M. (1997). Impaired auditory recognition of fear and anger following bilateral amygdala lesions. *Nature*, 385, 254–257.

Scherer, K. R. (1986). Vocal affect expression: a review and a model for future research. *Psychological bulletin*, *99*(2), 143.

Scherer, K. R., Johnstone, T., and Klasmeyer, G. (2003). Vocal expression of emotion. *Handbook of affective sciences*, 433-456.

Wild, B., Rodden, F. A., Grodd, W., & Ruch, W. (2003). Neural correlates of laughter and humour. *Brain*, *126*(10), 2121-2138.

Van Hooff, J. A. R. A. M. (1972). "A comparative approach to the phylogeny of laughter and smiling," in *Non-verbal communication*, ed. R. A. Hinde (Cambridge: Cambridge University Press, 209-237.

Vettin J., and Todt D. (2004). Laughter in conversation: features of occurrence and acoustic structure. *Journal of Nonverbal Behavior* 28, 93–115.

Table 1: Results of the independent t-tests comparing the acoustic properties of Spontaneous and Volitional laughter. Significant p values are highlighted in bold.

Acoustic Measure	**Condition**	**Mean**	**Std. Deviation**	**t**	**Sig. (2-tailed)**
Total Duration (sec)	Spontaneous	3.22	1.41		
	Volitional	1.62	.78	5.97	**<.001**
Percentage of Unvoiced Segments (%)	Spontaneous	71.51	12.20		

	Volitional	5.22	1.34	7.99	**<.001**
Harmonics to noise ratio (HNR (dB)	Spontaneous	7.14	2.26		
	Volitional	7.65	2.79	-.86	.391
F0 Mean (Hz)	Spontaneous	452.50	128.14		
	Volitional	289.12	61.86	6.89	**<.001**
F0 Variability (Hz)	Spontaneous	78.16	39.06		
	Volitional	52.06	26.14	3.33	**.001**
F0 Minimum (Hz)	Spontaneous	341.46	129.55		
	Volitional	209.26	4.66	5.84	**<.001**
F0 Maximum (Hz)	Spontaneous	592.28	161.35		
	Volitional	389.96	99.44	6.41	**<.001**
F0 Range (Hz)	Spontaneous	25.82	113.43		
	Volitional	18.70	93.58	2.86	.006
F0 Range (semitones)	Spontaneous	9.98	4.51		
	Volitional	1.52	4.50	-.51	.615
Burst Duration (secs)	Spontaneous	.07	.02		
	Volitional	.10	.02	-6.42	**<.001**
Spectral Centre of Gravity (Hz)	Spontaneous	1048.17	237.71		
	Volitional	881.60	343.60	2.39	.020
Intensity (dB)	Spontaneous	71.03	3.08		
	Volitional	74.88	2.32	-5.99	**<.001**

Table 2: Results of the independent t-tests for the affective and authenticity judgements

Acoustic Measure	Condition	Mean	Std. Deviation	t	Sig. (2-tailed)
Authenticity	Spontaneous	.69	.20		
	Volitional	.25	.17	9.82	**<.001**
Arousal	Spontaneous	4.26	.82		
	Volitional	2.67	.79	8.41	**<.001**
Valence	Spontaneous	4.85	.47		

	Volitional	3.69	.48	1.34	**<.001**

Table 3: Beta-weights and R^2 values of the regression analyses of acoustic measures and ratings, significant predictors are highlighted in bold.

Group	Acoustic Measure	Arousal	Valence	Authenticity
All laughter	Total Duration (sec)	**0.41*** **	**0.28***	0.25^{+}
	Percentage of Unvoiced Segments (%)	0.02	0.09	0.27
	HNR (dB)	-0.14^{+}	**-0.19***	0.19
	F0 Mean (Hz)	**0.43*** **	**0.55*** **	**0.42***
	F0 Variability (Hz)	-0.09	-0.01	-0.18

	Burst Duration (sec)	-0.12	-0.11	**-0.37***
	Spectral Centre of Gravity (Hz)	**0.33******	-0.07	-0.12
	Intensity (dB)	0.07	-0.03	0.14
	Adjusted R^2	**0.79******	**0.66******	**0.60******
Spontaneous laughter	Total Duration (sec)	**0.52******	**0.54*****	0.289
	Percentage of Unvoiced Segments (%)	-0.226	-0.204	-0.131
	HNR (dB)	0.063	0.132	-0.348
	F0 Mean (Hz)	**0.32***	0.282	0.242
	F0 Variability (Hz)	-0.215	-0.26	-0.006
	Burst Duration (sec)	0.064	0.136	0.032
	Spectral Centre of Gravity (Hz)	**0.47******	0.191	0.234
	Intensity (dB)	0.185	0.272	0.188
	Adjusted R^2	**0.68******	**0.44******	0.08
Volitional laughter	Total Duration (sec)	0.26^{+}	-0.045	-0.033
	Percentage of Unvoiced Segments (%)	0.154	0.25	0.243
	HNR (dB)	**-0.32***	**-0.62*****	**-0.72******
	F0 Mean (Hz)	0.192	0.48	0.496
	F0 Variability (Hz)	-0.15	-0.03	-0.271
	Burst Duration (sec)	0.007	0.162	0.212
	Spectral Centre of Gravity (Hz)	**0.54******	-0.279	0.022
	Intensity (dB)	0.122	0.026	0.142
	Adjusted R^2	**0.67******	**0.35*****	**0.38*****

$^{+}$p .1, *p .05, **p .01, ***p .001

Table 4: Beta-weights and R^2 values of the regression analyses of articulatory measures and ratings, significant predictors are highlighted in bold.

Group	Acoustic Measure	Arousal	Valence	Authenticity
All groups	Nasality	-.13	$-.21^{+}$	-.10
	Breathiness	**.2***	**.3*****	$.26^{+}$
	Mouth Opening	**.42******	$.23^{+}$	**.28***

	Adjusted R^2	**.23*****	**.21*****	**.14***
Spontaneous laughter	Nasality	.3$^+$	.16	**.47****
	Breathiness	**.45****	**.55*****	**.44****
	Mouth Opening	**.35***	**.37***	**.38***
	Adjusted R^2	.18$^+$	**.27****	**.27***
Volitional laughter	Nasality	-.3$^+$	-.07	-.01
	Breathiness	-.04	**.38***	**.34***
	Mouth Opening	**.63*****	.23	.30$^+$
	Adjusted R^2	**.36*****	**.15***	.13$^+$

$^+$p .1, *p .05, **p .01, ***p .001

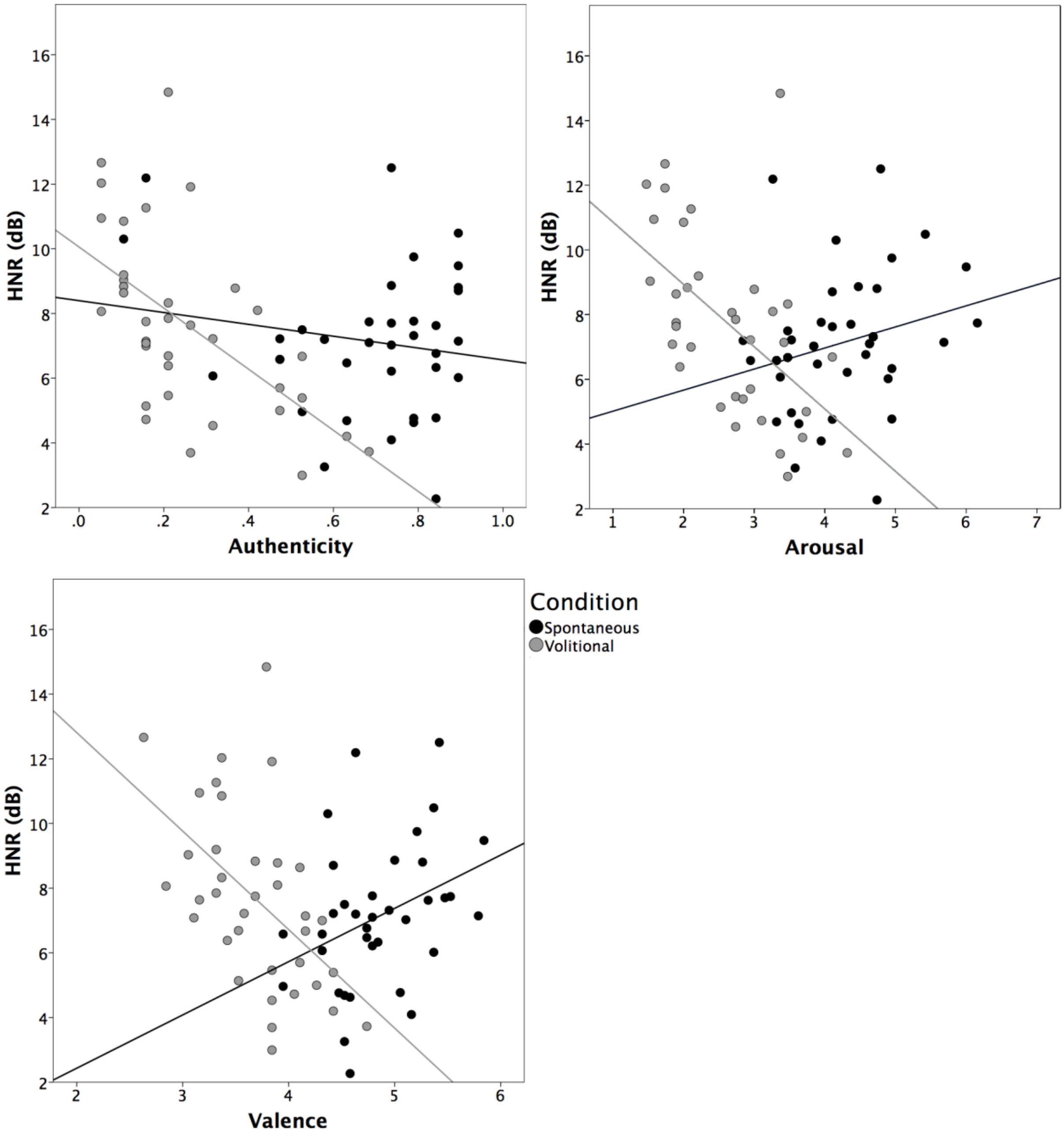

Figure 1: Scatterplots of HNR plotted against arousal, valence and authenticity for Volitional and Spontaneous laughter. Measures were positively correlated with valence (Pearson's *r*= .345, p = .039, other *p*s = *ns*) in Spontaneous laughter and negatively correlated with all three measures for Volitional laughter (arousal: Pearson's *r*= -.544, p = .001; valence Pearson's *r*=-*.523*, p = .001; authenticity: Pearson's *r*= -.585, p < 0.001).

Figure
Click here to download Figure: Fig1.tif