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Heaviness and the electric guitar: Considering the interaction between distortion and harmonic structures

In metal music studies, "heaviness" has been acknowledged an essential element of the genre. Commonly associated with the distorted guitar, most work on heaviness has concentrated on the instrument's sound. If respective research considered structural aspects of the guitar riff, then with a special focus on tempo, rhythm, tonality and form. This article analyses the interaction between distortion and harmonic structures on the electric guitar. Operationalising heaviness with a psychoacoustic model of sensory consonance, an acoustic experiment explores how guitar distortion affects acoustic features of harmonic structures. Since acoustic studies are limited in predicting perception, a listening test investigates distortion's influence on listener perception. The findings indicate that both increasing distortion level and harmonic complexity reduce sensory consonance, especially when acting together. Acoustically, distortion shows a slightly stronger effect strength than structure; perceptually, the ratio is dependent on person-specific characteristics. Metalheads seem to be only little affected by sensory dissonance.

Introduction

Although much as has been written on the electric guitar as a solo instrument in rock and metal music (Walser 1993; Waksman 2003; Herbst 2016, 2017b; Slaven and Krout 2016), its role as a rhythm instrument cannot be disregarded. Some work has explored structural, formal and harmonic characteristics of the rhythm guitar in metal music genres. For instance, Cope (2010) demonstrated different ways of rhythm guitar playing of early hard rock and heavy metal, and Elflein (2010) tracked structural and tonal developments of the rhythm guitar in metal music's history. Focussing on death metal, Berger (1999) studied genre-specific compositions and approaches to songwriting.

Another strand of research has investigated the phenomenon of "heaviness" as being closely related to the sound of the distorted rhythm guitar (Berger 1999: 58). Based on an acoustic analysis, Berger and Fales (2005) argued heaviness to be a result of piercing treble frequencies, great loudness and harmonic dissonance, which again complies with theoretical statements on metal music by Walser (1993: 45), Weinstein (2000: 23), Mynett (2013) and Williams (2015). Distortion was found to be the key determinant of heaviness since it affected all three parameters. Berger and Fales (2005: 194) concluded that distortion "simulates the conversion of the guitar from an impulsive to a sustained or driven instrument, and this transformation may be part of the acoustic correlate to the perceptional experience of heaviness". Distortion compresses the signal and produces harmonic and inharmonic overtones, sustain and a flatter dynamic envelope. These acoustic effects result in a brighter sound, roughness and amplitude fluctuations, which are perceived as noise surrounding the tone (Berger and Fales 2005: 184). By tracking the electric guitar's acoustic changes in metal history, Herbst (2017a) confirmed more distortion and an extended frequency range to have increased heaviness over time. Furthermore, layering of guitar tracks became common practice negatively affecting intelligibility but increasing the spectral density (Mynett 2012; Herbst 2017a). Very slow or fast tempos and obscured tonality contribute to the perception of heaviness too (Berger 1999: 58f; Hagen 2011: 185). Modality has a bearing on heaviness and thus many harder metal genres prefer darker minor modes such as Phrygian and Locrian (Walser 1993: 46). In the case of black metal, Hagen (2011: 184) highlights a preference for "full chord voicings, which produce a denser and less clearly resonant timbre when played through distortion". Especially minor chords are more common in black metal than in most other metal genres. Moreover, guitar techniques such as "buzz-picking" create a droning or piercing quality (Kahn-Harris 2007: 32; Hagen 2011: 187). Considering the great importance of distortion for heaviness, Berger and Fales (2005: 182f) argue:

> "While some features of heavy metal have remained the same over time, what listeners specify as the quality of 'heaviness' in distorted guitar timbres has been observed to increase incrementally over the genre's history. As Berger notes (1999: 58-60), metalheads almost universally assert that the distorted guitar timbres of 1970s heavy metal were heavy, those of the 1980s reached a new level of heaviness, and those of the 1990s were heavier still."

Although metal music has become heavier over time, the means of achieving heaviness differed in metal's subgenres. Whereas the development from heavy metal to death metal was characterised by a significant shift to lower frequencies (Kahn-Harris 2007: 32; Herbst 2017a), black metal embraced a thin, brittle and harsh guitar tone to distinguish itself from other metal genres (Hagen 2011: 187; Reyes 2013). Apart from the guitar, other stylistic means define subgenres as well, be it the use of "blast beats" (Hagen 2011: 186), vocal screams or growls (Walser 1993: 42; Berger 1999: 58), distorted vocal voices and bass guitars (Elflein 2010: 250ff; Weinstein 2011: 41f) or the number of form parts (Berger 1999: 63ff). Heaviness specific to metal's subgenres thus "is a discursive category that implies a collection of sonic characteristics and compositional, or performative, elements" (Mynett 2013: 40).

One constant in most metal guitar playing since the early 1970s has been the harmonic vocabulary. As a fifth interval being neither major nor minor, the power chord has been the most common chord in metal genres (Walser 1993: 43; Berger 1999: 184f; Kahn-Harris 2007: 31f) except for black metal (Hagen 2011). Berger (1999: 185) notes that the fifth interval can be replaced by the tritone and perfect fourth, and that the "third, as well as the seventh and the upper extensions, are always absent from the power chord". Considering the historical development, Moore (2001: 148f) observed "heavy metal's tendency towards greater use of guitar distortion" and its "use of power chords, normally combined with distortion, which underpins faster tempi, and which in the last decade has become replaced by individual lines." Other authors (Walser 1993; Berger and Fales 2005; Cope 2010; Elflein 2010) share this view. Regarding chord structures, much metal music has become less complex while at the same time the riffs became more distorted (Herbst 2017a).

Although distortion is likely to touch both the harmonic and the sonic centre of the genre, so far little research has concentrated on the perception of distorted guitar chords and metal music's harmonic structures (Berger 1999; Lilja 2005, 2015; Berger and Fales 2005; Juchniewicz and Silverman 2011; Herbst 2016). From a music theory perspective, intervals and chord structures have been essential in discussing consonance (Sethares 2005). For intervals, the complexity of frequency relation correlates with perceived dissonance (Roederer 2008: 170ff) whilst for chords the affinity of tones and the fundamental-note relation matter (Terhardt 1984: 278f). Empirical studies confirmed the decreasing sonority of major, minor, diminished and augmented triads in Western music (Roberts 1986; Cook and Fujisawa 2006). To include the tone quality in the estimation of sonority, Terhardt (1984) introduced an extended concept of musical consonance. Drawing upon Helmholtz' (1863) work, Terhardt (1984: 282) defined *sensory consonance* "as the more or less complete lack of annoying features of a sound; it is pertinent to such sensory parameters as roughness and sharpness (i.e., on the physical side, amplitude fluctuations and presence of spectral energy at high frequencies)". Aures (1985) differentiated this model by empirically extrapolating its four main components: roughness, sharpness, tonalness and loudness. Sensory consonance, or pleasantness as termed by Aures, is decreased by high values of roughness, sharpness and loudness. In contrast, high tonalness increases sensory consonance (Aures 1985: 289). Such a psychoacoustic perspective highlights several aspects underrepresented in a music theory perspective, which merely concentrates on structures (Berger 1999: 193ff). Considering psychoacoustic aspects unfold consonance and dissonance not falling into strictly defined categories but rather being perceived on a continuum. Similarly, the perception of sounds is subject to personal characteristics and change (Sethares 2005: 80).

A recent study by Czedik-Eysenberg, Knauf and Reuter (2017) has explored the "heaviness" of music irrespective of a specific genre by correlating a listening test with a psychoacoustic analysis of the same audio samples. The results showed that percussive elements such as intensive drumbeats but also spectral fluctuations are crucial for the perception of heaviness. The spectral distribution played an important role as well. In compliance with Berger and Fales' (2005: 194) qualitative study, a strong high-energy content was found to contribute to heaviness, as did a pronounced low end. Also confirmed was Berger and Fales' (2005: 194) claim of compression resulting in a flat envelope curve. The singing further was of high importance since screaming and rough vocal styles like growling were perceived as particularly hard. Regarding person-related factors, men were generally found to perceive the tracks as less "heavy" as women did. Yet, there were no statements for the electric guitar in rock and metal music although according to the authors the participants mentioned "distortion" and "specific guitar riffs" as important factors for heaviness in their open statements.

Since distortion extends the harmonic content of a guitar signal (Berger and Fales 2005), most research on the perception of distorted guitar chords has studied the sound's spectral composition in theory or by acoustic analysis. On the theoretical ground of Helmholtz (1863), the power chord produces less dissonant partials than more complex interval relations do because many of the partials coincide (Lilja 2005: 10f). Even added combination tones (Roederer 2008: 43ff) hardly ever diminish the chord's sonority substantially. On the contrary, distortion increases the chord's powerful sensation, making it ideal for metal riffs (Walser 1993: 43ff). Although the power chord possesses no tonality, some research has observed a latent major character (Berger 1999: 197; Juchniewicz and Silverman 2011; Lilja 2015). In an empirical investigation, Juchniewicz and Silverman (2011) found participants to perceive terminal power chords as major. An explanation for this impression can be drawn from the harmonic series with the major third being the fourth overtone (Lilja 2015: 396). Recent spectrographic analysis has indicated the harmonic structures of power chords and major chords to be almost identical due to the combination tones produced by distortion (Herbst 2016: 185ff). Minor chords, however, are regarded as more dissonant because of the more complex interval relations (Lilja 2005: 20; Herbst 2016: 190ff). To sum up, the spectral characteristics of the distorted sound arguably have tempted many guitarists to play simple harmonic structures, mostly single notes and power chords, rather than complex intervals, triads and extended chords (Berger 1999; Moore 2001; Lilja 2005, 2015; Elflein 2010; Herbst 2016).

The current discussion of heaviness in metal music studies is widely missing out the perspective of music psychology; moreover, research in metal music studies has not yet provided empirical evidence. Especially listener perception has been an understudied area of research. So far, heaviness is not clearly defined and likewise the role of harmonic consonance is unclear. Considering atonal guitar riffs, heavily distorted tones and rapid rhythms, dissonance of some sort appears important to the notion of heaviness. In the case of the guitar, bringing together both areas of research – heaviness and sensory consonance – is still outstanding. Yet, many parallels exist on closer inspection. The compressed and sustained sound of the distorted guitar matches the parameter *loudness* in Terhardt's (1984) and Aures' (1985) model of sensory consonance whereas the guitars' extended treble-range corresponds to *sharpness*. Closely related are added overtones and noise causing *amplitude fluctuations* and *roughness*. This enhanced overtone spectrum and the chord's obscured tonality correspond to the parameter *tonalness*. Therefore, heaviness strongly correlates with the psychoacoustical model. This assumption is supported by Czedik-Eysenberg, Knauf and Reuter's (2017) recent study on musical heaviness.

This study analyses the interaction between distortion and harmonic structures on the electric guitar. It explores the influence of distortion on guitar chord structures with an integrated acoustic and listening experiment (Eysenberg, Knauf and Reuter 2017), intending to identify acoustic features potentially causing sensory dissonance as an element of heaviness. Whilst acoustic analyses can provide valuable insights into features affecting the perception, the actual impact of distortion cannot be determined without any verification through listeners. Thus, the acoustic experiment is extended by a listening experiment. Specifically, the following research questions are addressed: How does distortion alter the acoustic features of guitar chords? What role does structure play in relation to tone quality? How does the level of distortion affect listeners' ratings of pleasantness? What acoustic aspects affect the liking of guitar sounds? Which person-related factors influence the perception of distorted guitar chords?

Method

This research follows a data triangulation approach (Denzin 1978: 300). The results of the acoustic and listening experiments are first reported separately, and in a next step, integrated in the triangulation and discussion sections.

Terminology

Terms like *sound*, *timbre* and *tone* can easily be confused for their ambiguous understanding regardless of formal definitions (Houtsma 1997). *Sound* is generally understood as every acoustic phenomenon that strikes our ears (Peirce 1996: 223) whereas *timbre* commonly is associated with the sound quality that differentiates musical instruments and voices at the same loudness and pitch (Howard and Angus 2001: 210f). This is slightly different with the *tone* as it refers to the various qualities of an instrument or vocal sound (Mueller 2015: 22f). In this study, *tone* or *tonal quality* is the term for the different levels of guitar distortion: clean, overdriven and distorted. In addition, the term *structure* is relating to the different guitar chord structures.

Data

Both parts of the study were based on experimental audio files. To systematically investigate the effect of distortion on guitar chords, five different structures on the same root C3 were recorded: 1. single notes (abbreviated sn), 2. power chords (pc), 3. major chords (ma), 4. minor chords (mi), 5. altered dominant-seventh chords without fifth but with added augmented ninth (alt). All chords were played with similar voicings for best possible comparability of interval structures. Each chord was recorded with three guitars: a Fender American Standard Stratocaster, a Music Man John Petrucci and a Gibson Les Paul Standard. All guitars had humbucker pickups in the bridge position. The signals were recorded into Apple Logic Pro X with a Roland OctaCapture audio-card and re-amped with the Palmer Daccapo box into five valve amplifiers: Laney GH50L, Marshall JCM2000 TSL100, Mesa Boogie Triaxis, Orange Dual Terror and Peavey 5150 MKI. These amplifiers covered a range of traditional and contemporary rock and metal guitar tones. Transistor and modelling amplifiers were not considered due to their different spectral and dynamic characteristics (Berger and Fales 2005: 185). All signals were recorded with a clean, overdriven and distorted setting in the same amplifier channel. For creating the distorted tone, a Fulltone OCD pedal was added to the overdrive setting to boost the amplifiers' valves. The gain differences were similar from clean to overdrive and from overdrive to distortion to ensure sufficiently distinct tones. The signal ran into a Marshall 1960 cabinet with Celestion Vintage 30 speakers. It was recorded with a Shure SM57 dynamic microphone. In the export, all audio files were normalised to compensate for slightly different amplifier volumes. As normalisation reacts to peak volumes, the average RMS volumes were hardly affected. The total sample consisted of 270 audio files. For the listening experiment, the samples recorded with the Stratocaster guitar and the Laney amplifier were used.

On the evaluation form of the listening experiment, the participants reported their gender, age and higher education course. The preference for rock and metal music was assessed on a 5-point scale, labelling (1) as "strong disliking" and (5) as "strong liking". Moreover, the participants declared whether they played the electric guitar, and if so, how much experience they had. During the listening test, the participants rated the examples on a 10-point scale with labels on the anchors, signing left (1) as "unpleasant" and right (10) as "pleasant". Every chord was rated three times to minimise order effects (Krumhansl, Bharucha and Kessler 1982). After the rating, the participants described how they experienced the experiment and what tonal qualities they believed had affected their perception.

Acoustic experiment

The recorded audio files were analysed with feature extraction functions of modern music information retrieval technology. With the MIR (Lartillot and Toiviainen 2007) and Loudness (Genesis 2009) toolboxes five parameters were extracted that complied with Terhardt's (1984) and Aures' (1985) model of sensory consonance.

Roughness, as defined by Helmholtz (1863) and extended by Plomp and Levelt (1965), is considered the most important attribute for dissonance since it reduces a sound's smoothness by beatings of adjacent partials that excite the same critical band in the auditory system. Therefore, musical sounds with a rich harmonic spectrum are prone to produce roughness and amplitude fluctuations (MacCallum and Einbond 2008: 203). Roughness was calculated with the MIR-Toolbox using Sethares' (2005) algorithm. Spectral fluctuation strength was gathered with the MIR-Toolbox's function of calculating the distance between spectra of successive frames (Lartillot 2014: 60). Zwicker and Fastl (2007: 245) advocate *sharpness* as the most important factor regarding sensory consonance. Showing in the spectral content of a sound, sharpness can be computed by the spectral centroid as the mean frequency of the spectrum (McAdams, Depalle and Clarke 2004: 191). A higher centroid caused by loud upper partials correlates with a brighter texture that is likely to be perceived as unpleasant because the human ear is most sensitive in the range between 2 kHz and 5 kHz (Zwicker and Fastl 2007: 17ff). For measuring sharpness, the spectral centroid was determined with the MIR-Toolbox, concurring with empirical findings (Grey and Gordon 1978; Schubert and Wolfe 2006). *Loudness* is a subjective parameter reducing sensory consonance related to the sensation of roughness and sharpness (Aures 1985). It was calculated with the Loudness-Toolbox (Genesis 2009) according to the ASNI S3.4-2007 norm (Moore, Glasberg and Baer 1997). *Tonalness*, defined by the "closeness of the partials to a harmonic series" (Sethares 2005: 79f), is the only parameter increasing consonance. It was extracted by an inversion of the MIR-Toolbox's inharmonicity algorithm (Lartillot 2014: 143f). The modified algorithm estimated the root note and analysed the amount of energy close to the harmonic series compared to the rest of the signal (Sethares 2005: 79f). With 270 audio files and 5 parameters, 1,350 acoustic values were extracted.

Listening experiment

171 students (95% undergraduate) aged between 18 and 39 (M = 22.06, SD = 3.33, 53% women) from six German higher education institutions participated in the listening test. 76%

were studying music-related courses (N = 127), the remaining 24% were enrolled in arts education (N = 16), social work (N = 11) and other courses (N = 17). 21% played the electric guitar. The total sample consisted of 6,156 chord ratings. There was a slight preference for rock and metal music (M = 3.21, SD = 1.33) without significant differences between the sexes ($t(170) = -1.76$, p = .08, d = 0.27). Guitar players' fondness of rock and metal was by far above average ($t(170) = 4.46$, $p < .001$, d = 0.83). The guitar playing experience and preference for rock and metal correlated ($r_s(171) = .31$, $p < .001$). For data analysis, three scales with a very good internal consistency were defined: clean (α = .92), overdrive (α = .97) and distortion (α = .97). The participants' writings on their listening experience were interpreted with qualitative content analysis.

Results

Acoustic experiment

Analysing musical structures required studying the role of the equipment first to test its influence on the chords' acoustic features. The ANOVA *F*-test demonstrated insignificant differences of all five parameters for the guitar models. Similarly, the amplifiers did not show significant variance in roughness, spectral flux and tonalness. Very small and medium differences were found in loudness ($F(4, 89) = 3.04$, p = .02, η_p^2 = .04) and in the spectral centroid ($F(4, 89) = 6.30$, $p < .001$, η_p^2 = .09). For both parameters, the Tukey HSD post-hoc test reported the Orange Tiny Terror being quieter and less bright than the other amplifiers. Since both aspects of sound can be controlled by the amplifier's setting, the equipment had a negligible effect not worth considering in subsequent tests.

According to theory, distortion should affect the parameters of sensory consonance for all chords. Table 1 displays the influence of increasing distortion levels on all structures. Only tonalness, the parameter most closely connected to musical structure, increased almost constantly with greater structural complexity, indicating complex interval relations being more dissonant. Loudness does not depend on structure apart from the number of notes (Herbst 2016: 118ff). The power chord with only two notes was the loudest, which can be explained by the hard picking performed with a solid muting technique. Since spectral centroid is affected by the pitches, the chords with higher notes are perceived as brighter. Consequently, the altered chord was duller than the major and minor chord. Roughness, the main parameter constituting dissonance in Helmholtz' paradigm, did not coincide with the theory. Neither did spectral flux increase with greater structural complexity. Yet, the high values for all structures indicate spectral flux to be related more to the tonal quality than to the structure.

Table 1: Correlation matrix of tone and parameters of sensory consonance for all structures.

	sn	pc	ma	mi	alt
Roughness	.74	.79	.84	.66	.75
Spectral flux	.94	.94	.94	.91	.89
Spectral centroid	.78	.85	.89	.88	.85
Loudness	.85	.92	.89	.87	.85
Tonalness	–.35	–.53	–.64	–.84	–.81

Note: All correlations on probability level $p < .001$, N = 270.

For determining the interrelation between harmonic complexity, tonal quality and sensory consonance, several two-way ANOVAs were calculated (Table 2). Structure and tone strongly interacted in the case of spectral flux, which complies with the correlational results before. Roughness and tonalness also showed strong interactions between structure and tone.

These results can be explained with the three parameters being connected to interval relations. In contrast, loudness and spectral centroid are mainly dependent on the amplifiers' settings, and thus structure and tone did only interact with a medium effect for spectral centroid and with a minimal effect for loudness.

Table 2: Between-subjects-effects of two-way ANOVAs of the parameters of sensory consonance.

	Structure			Tone			Interaction structure * tone			Corrected Model		
	df	*F*	η_p^2	df	*F*	η_p^2	df	*F*	η_p^2	df	*F*	η_p^2
Roughness	5	55.64	.53***	2	241.44	.66***	10	9.22	.27***	17	50.19	.77***
Spectral flux	5	164.08	.77***	2	855.00	.87***	10	24.71	.50***	17	163.38	.92***
Spectral centroid	5	31.30	.38***	2	597.04	.83***	10	2.42	.09**	17	80.87	.85***
Loudness	5	5.46	.10***	2	625.41	.83***	10	1.09	.04ns	17	75.82	.84***
Tonalness	5	362.12	.88***	2	119.53	.49***	10	5.32	.17***	17	123.70	.89***

*Note: * p < .05, ** p < .01, *** p < .001, N = 270, df = 252.*

The relative impact of harmonic complexity and tonal quality was estimated by categorical regression models (Table 3). As indicated before, structural complexity affected the parameter of tonalness much more than the tone did. In contrast, sharpness and loudness depended significantly more on distortion level. For the parameters roughness and spectral flux, the ratio between structure and tone was more balanced, even if the level of distortion affected fluctuation strength more. Summing up, the tonal quality had a greater impact on all parameters of sensory consonance, except for tonalness, than the interval structure had.

Table 3: Categorical regression models of the parameters of sensory consonance.

		Regression				ANOVA	
		Beta	*F*	Sig.	adj. R^2	*F*	Sig.
Roughness	Structure	.48	126.84	< .001	.66	131.73	< .001
	Tone	.66	455.89	< .001			
Spectral flux	Structure	.50	358.10	< .001	.85	221.26	< .001
	Tone	.78	684.55	< .001			
Spectral centroid	Structure	.26	73.29	< .001	.78	192.61	< .001
	Tone	.85	1857.07	< .001			
Loudness	Structure	.10	11.15	.001	.81	285.17	< .001
	Tone	.90	4448.84	< .001			
Tonalness	Structure	–.84	1046.01	< .001	.81	191.73	< .001
	Tone	–.32	89.36	< .001			

Note: Parameters of sensory consonance were parametric, structure and tonal quality non-parametric (ordinal).

Listening experiment

The data of the listening experiment provided insights into the influence of tonal quality on the perception of guitar chords. As the descriptive values (Table 4) show, the major chord played with a clean tone was perceived as most pleasant, followed by the power, minor and altered chord. Regarding the overdriven and distorted tones, the perceived pleasantness followed the order from least to most complex structure: power, major, minor and altered chord. The influence of tonal quality was determined through multiple *t*-tests. Adding overdrive to clean tones led to different ratings of the chord types. For minor and altered chords, the pleasantness was reduced with a medium to large effect whereas for the power and major chord the effect was small. Increasing the gain from overdrive to distortion had a small to medium effect on all chord ratings but least on the power chord. In other words, the perceived pleasantness of simple chords was less affected by overdrive and distortion than it was for more complex structures. On the scale level, the effect from clean to overdrive was twice as high as from overdrive to distortion.

Table 4: Descriptive statistics and mean differences of perceived chords' ratings.

	Mean clean	Mean overdrive	Mean distortion	Difference clean and overdrive	Difference overdrive and distortion
power chord	7.40 (1.48)	6.76 (1.97)	6.06 (2.48)	t = 5.16; p < .001; d = −0.37	t = 8.41; p < .001; d = −0.31
major chord	7.52 (1.46)	6.64 (2.03)	5.61 (2.59)	t = 6.18; p < .001; d = −0.50	t = 10.74; p < .001; d = −0.44
minor chord	6.96 (1.60)	5.05 (2.22)	3.89 (2.52)	t = 11.89; p < .001; d = −0.99	t = 12.57; p < .001; d = −0.49
altered chord	6.06 (2.04)	4.40 (2.26)	3.35 (2.46)	t = 11.22; p < .001; d = −0.77	t = 11.12; p < .001; d = −0.45
scale	6.99 (1.41)	5.61 (2.00)	4.72 (2.34)	t = 10.33; p < .001; d = −0.80	t = 13.26; p <.001; d = −0.41

Note: N = 171, df = 170; values in brackets are standard deviations.

Comparing the mean differences between the chord types (Table 5) revealed major and power chords to differ little irrespective of the tonal quality. The differences between minor and altered chords were medium with clean tones and small for both distorted tones. In contrast, the small to medium differences between clean major and minor chords increased to large effects with overdriven and distorted tones.

Table 5: Effects (Cohen's d) of mean differences between chords for all three tones.

	Clean			Overdrive			Distortion		
	pc	ma	mi	pc	ma	mi	pc	ma	mi
ma	0.08			−0.06*			−0.18***		
mi	−0.29***	−0.37***		−0.82***	−0.75***		−0.87***	−0.67***	
alt	−0.75***	−0.82***	−0.49***	−1.11***	−1.04***	−0.29***	−1.10***	−0.90***	−0.22***

*Note: * p < .05, ** p < .01, *** p < .001, N = 171, df = 170.*

Regression analyses were computed to estimate the impact of person-related factors. The model explained little variance for clean tones ($F(1, 159) = 4.64$, $p = .03$, adj. $R^2 = .02$). Only music preference was identified as a significant predicator ($\beta = .17$, $p = .03$). Two further regression models reported more variance for overdriven (49%) and distorted (54%) tones (Table 6).

Table 6: Stepwise regression analyses of overdriven and distorted tones.

	Overdrive				Distortion			
	adj. R^2	*B*	*SE B*	β	adj. R^2	*B*	*SE B*	β
Model 1	.47***				.49***			
(Constant)		2.29	0.30	***		0.77	0.35	*
Preference		1.03	0.09	.68***		1.23	0.10	.70***
Model 2	.49***				.53***			
(Constant)		0.15	0.77	ns		−2.18	0.87	*

Preference	0.98	0.09	.65***		1.17	0.10	.66***
Age	0.10	0.04	.17**		0.14	0.04	.20***
Model 3				.54***			
(Constant)					−2.68	0.88	**
Preference					1.14	0.10	.65***
Age					0.13	0.04	.18**
Gender					0.65	0.26	.14**

Note: *Gender was coded 1 = women, 2 = men, * $p < .05$, ** $p < .01$, *** $p < .001$, N = 159.*

Person-related factors proved to be affecting the ratings significantly. A preference for rock and metal was the strongest indicator for a liking of overdriven and distorted tones. Whilst the preference had no significant effect on the ratings of the clean guitar, the effect was medium for overdriven ($F(4, 166) = 34.67$, $p < .001$, $\eta_p^2 = .46$) and distorted ($F(4, 166) = 37.21$, $p < .001$, $\eta_p^2 = .47$) tones. Age was a minor predicator for overdriven and distorted tones, gender only for the distorted chords.

Although not valid predicators in the regression models, certain person-related variables still affected the ratings. The effect of gender was small for the overdriven ($t(169) = -2.19$, $p = .03$, $d = 0.34$) and medium for the distorted ($t(169) = 3.49$, $p = .001$, $d = 0.54$) tone. For guitarists, the pleasantness was increased with a medium effect for overdriven tones ($t(169) = 3.90$, $p < .001$, $d = 0.71$) and with a strong effect for distorted ($t(169) = 4.74$, $p < .001$, $d = 0.89$) chords. The playing experience also increased the liking of both tones (overdrive: $r_s(171) = .28$, $p < .001$; distortion: $r_s(171) = .33$, $p < .001$) with a weak to medium effect.

154 of the 171 participants described their listening experience. 250 codes were extracted. Using quantitative content analysis, these codes were divided into the four main categories ‘tonal characteristics’, ‘listening habits’, ‘effects and associations’ and ‘context’. Within ‘tonal characteristics’, most of the statements addressed issues related to frequency. Apart from an unbalanced sound, sharpness was emphasised by describing the unpleasant treble frequencies resulting from distortion. Other parameters of the psychoacoustic model such as clarity, roughness and loudness were also found in the answers. Within the second category, the statements generally suggested that ‘listen habits’ were affecting the perception. Metal enthusiasts and electric guitarists stressed to have acquired a high tolerance towards dissonant or harsh sounds due to familiarisation whereas other participants saw the reason for disliking distorted tones in their socialisation, especially their background in classical music. The third category comprised of ‘effects and associations’, both predominantly ascribed with negative attributes such as exhaustion, painfulness, aggressiveness, menace, inner disturbance, hardness, coldness or emotions such as fear. Less negative were the statements about associations as they included references to songs, musical genres, persons or situations. In the fourth category, the need for a larger musical ‘context’ was stressed to adequately rate the sounds. A few participants felt the artificial listening situation to have influenced their ratings.

Data triangulation

Using identical sound files permitted data correlation of the acoustic and listening experiments. In the total sample, Spearman correlation indicated a close connection between the listeners’ ratings and most of the acoustic values (Table 7).

Table 7: Correlation matrix of sociodemographic data and parameters of sensory consonance.

	Roughness	Spectral flux	Spectral	Loudness	Tonalness	Correlation

			centroid			with music preference
Total sample (N = 171)	−.41*	−.90***	−.74***	−.67***	.67***	n/a
Rock / metal preference (N = 70)	.06^{ns}	−.53***	−.30^{ns}	−.19^{ns}	.30^{ns}	n/a
No rock / metal preference (N = 84)	−.58***	−.94***	−.79***	−.77***	.74***	
Female (N = 91)	−.46**	−.92***	−.78***	−.71***	.69***	Gender:
Male (N = 80)	−.23^{ns}	−.79***	−.59***	−.50**	.55***	.13^{ns}
Guitarist (N = 35)	.13^{ns}	−.51***	−.25^{ns}	−.15^{ns}	.23^{ns}	Guitarist:
No guitarist (N = 136)	−.45**	−.92***	−.76***	−.69***	.70***	.31***
Age up to 24 (N = 132)	−.42**	−.91***	−.75***	−.68***	.68***	Age:
Age above 24 (N = 31)	−.18^{ns}	−.76***	−.58***	−.48***	.52***	.13^{ns}

Note: ** p < .05, ** p < .01, *** p < .001; rock / metal preference: persons with value below 3; no rock / metal preference: persons with value above 3.*

In compliance with the psychoacoustic model, all parameters but tonalness reduced the pleasantness of the chords. Roughness correlated with the listeners' ratings least. In contrast, spectral flux as an alternative parameter for roughness had an almost perfect correlation. Strong effects of spectral centroid and loudness were also confirmed to reduce pleasantness. Apart from the single parameters, Spearman correlation demonstrated a close connection between perceived pleasantness and structural complexity ($r_s(36) = -.63$, $p < .001$) as well as between pleasantness and tonal quality ($r_s(36) = -.72$, $p < .001$). Thus, more complex chords and greater distortion levels negatively affected sensory consonance for many listeners.

Person-specific variables played an important role. It was the musical preference mainly determining the perception of distortion. None of the parameters except for spectral flux significantly decreased the liking for metalheads whereas for participants not fond of rock and metal music every parameter affected their perception significantly. Regarding gender, men seemed to be affected less by increasing distortion levels if only with small differences. Since neither the correlation between gender and music preference nor the *t*-test demonstrated significant differences, gender seems to be influential for the perception of distorted guitar chords. Participants playing the electric guitar differed from those not playing, which is probably due to the guitarists' higher liking of rock and metal music. Age was another influencing factor not correlated with musical preference. The older participants of this sample did not perceive distorted tones as unpleasant as the younger ones.

Discussion

This research has analysed the interaction between distortion and harmonic structures on the electric guitar by exploring the influence of distortion on the sensory consonance of various guitar chords. In line with the expectation, both the acoustic and the listening experiment confirmed increasing distortion level and harmonic complexity to reduce sensory consonance, especially when acting together. Acoustically, distortion showed a slightly stronger effect strength than structure; perceptually, the ratio was dependent on person-specific characteristics. The findings comply with the little research on distorted guitar chords and musical heaviness. As was to be expected, overdriven power chords were generally not perceived as unpleasant, not even with increasing distortion levels (Walser 1993; Berger and Fales 2005; Lilja 2005, 2015). Overdrive affecting major chords little was a finding that supports the assumption of slightly overdriven major chords being commonly perceived as not utterly dissonant. Also in line with the theoretical and spectral-analytical findings of Lilja (2005, 2015) and Herbst (2016), large differences between major and minor chords existed when played with overdriven and distorted tones. Regarding heaviness, most results complied with the study by Czedik-Eysenberg, Knauf and Reuter (2017). In both studies, spectral fluctuations, sharpness and a high loudness have proved to affect the perception considerably. The parameter tonalness affected the participants of this study much more, which can be explained by the systematic variation of harmonic content. In contrast to Czedik-Eysenberg, Knauf and Reuter's (2017) study on musical heaviness, the high importance of roughness could not be confirmed. This issue requires further discussion.

Acoustic parameters

Reflecting on the parameters of sensory consonance, *roughness*, the main factor in psychoacoustic consonance theory in Helmholtz' (1863) tradition, does not appear an optimal indicator for dissonance. It neither fitted the theoretical model nor correlated with the listeners' ratings as strongly as the other parameters did. This problematic role of roughness has been observed by Parncutt (2006: 205f) too. He claimed the clear identifiability of the root being the decisive factor of consonance thus highlighting the importance of *tonalness*. Evidence for this argument was found in the participants' statements stressing distortion to reduce transparency and clarity. This further complies with the strong influence of tonalness evidenced in the analyses.

In the case of the electric guitar, *spectral flux* in combination with *loudness* is likely to be an important contributor to dissonance. The natural fluctuations resulting from interval relations are increased by distortion's compression effect, accentuating the uneven envelope by acceleration and greater density, ultimately diminishing the chord's sonority. In the listening test, spectral fluctuation demonstrated its central role by an almost linear negative correlation with the ratings of pleasantness. Loudness was confirmed a decisive factor as well. Although it correlated with the listeners' ratings less than all other parameters but roughness, many participants stressed its effect in their open statements. Hence, for the dissonant effect of overdriven and distorted tones, temporal and loudness-related aspects need to be regarded in addition to the spectral aspects that are commonly considered.

Sharpness clearly affected sensory consonance as proved by the strong correlation between acoustic data and subjective ratings. For many participants disliking distortion, sharpness was the decisive parameter. The open answers described unpleasant treble and even physical pain. These sensations stem from the human auditory system. Vital for speech clarity, the ear is most sensitive in the frequency between 2 kHz and 5 kHz; intensity in this range can therefore be hurting (Zwicker and Fastl 2007: 17ff). However, the ear's sensitivity unlikely is the overarching criteria since there has been great variance regarding music preferences. Albeit highly depending on familiarisation, sharpness still seems to be a major reason for disliking guitar distortion.

The triangulated results point to loudness, spectral centroid, spectral flux and tonalness being suitable parameters for predicting the sensory consonance of electric guitar chords played with different tones. Spectral centroid and loudness are reliable predicators for the impact of tonal quality, whereas for the effect of harmonic structures, spectral flux and tonalness are better suited.

Person-related factors

The results highlight the relevance of person-related factors, most of all musical preferences and familiarisation. Participants less rock and metal enthusiastic were greatly affected by the acoustic changes resulting from guitar distortion. Spectral fluctuation strength was the parameter reducing pleasantness by far the most. To get an aural impression, spectral flux resembles the buzzing quality that most commonly is associated with the guitar playing style in black metal (Hagen 2011: 187). As this sound is special and unlikely to be favoured by all metal listeners, it might explain why spectral flux is the only one of the five parameters affecting metalheads. Apart from the unpleasant fluctuations, no other parameter significantly reduced the liking of distorted tones for metal enthusiasts. Although not significant, sharpness and obscured tonality were the parameters prone to affect metalheads as well. Again, these are sonic attributes most commonly associated with the aesthetics of black metal and its practice of playing full chords with distorted guitars (Hagen 2011: 184). Thus, this spectral aesthetics may divide metal fans. For proving evidence, however, more detailed data is needed to differentiate between music preferences. Therefore, future research will be confronted with the task to explore guitar distortion's effects on sensory consonance with listeners of different subgenres. Irrespective of the various subgenres, the results of this study support Berger's (1999: 215ff) findings of metal musicians perceiving musical structures very differently from the standard Western music theory. Likewise, it appears that metalheads perceive distorted tones differently than people not fond of this music.

Gender is another variable worth discussing. The results demonstrated men and women strongly diverging in their liking of overdriven chords and even more of distorted tones, which complies with the findings of Eysenberg, Knauf and Reuter (2017). Men generally were affected less by distortion, and this finding kept consistent for all five parameters. Whilst the data cannot provide an explanation grounded in empirical evidence, it can only be speculated that different musical preferences played a crucial role. Since the preference was gathered with little detail, it might be that in this sample the women favoured rock and lighter subgenres of metal whereas men were rather drawn to heavier styles (Weinstein 2000: 47). Representative statistics of the German Music Information Centre (MIZ 2015) support this assumption by demonstrating both a comparable liking of rock music for women and men over 13 years and a significant higher liking of hard rock and heavy metal for men. This largely explains the gender effects found being subject of musical preferences.

Heaviness and musical structure

The introductory deliberations indicated a close connection between heaviness and the sonority of distorted guitar tones. The results confirm Terhardt's (1984) and Aures' (1985) psychoacoustic model of sensory consonance to adequately address both aspects. The data suggest that harmony, widely disregarded in debating heaviness yet, needs to be considered. It is a means of shaping heaviness like other structural features.

Berger and Fales (2005: 182f) argued metal music having become heavier in genre history and distortion being the prime element for increased heaviness. This complies with Gracyk's (1996: 103f) argument of rock musicians having exploited noise to develop the genre. The empirical results of this study indicate that distortion strongly contributes to perceived heaviness but without a perfect correlation because the effect becomes weaker once the guitar is already overdriven. Furthermore, the data show distortion on its own is hardly affecting listeners favouring rock and metal music. For those enthusiasts, it takes structural dissonance as well to reduce pleasantness, which complies with Berger's (1999) analysis of death metal compositions. Death metal bands would aim at disturbing "the listener's sense of tonality with unexpected half-steps and tritones", defying "the listener's tonal expectations [of] the pitch axis" (Berger 1999: 62f). At least in the death metal tunes Berger (1999: 229) analysed, the compositional focus was on single notes and intervals, and power chords often were understood as melodic fragments rather than in terms of harmony. Different intervals in extension of power chords were preferred over chords and thus chord progressions either were felt not in the traditional sense or were deliberately refused (Berger 1999: 229). Although complex chords are currently not common in many metal genres, the present study demonstrates distortion to extend the heaviness of musical structures irrespective of being intervals or full chords. For metalheads, as can be concluded, structure largely determines heaviness but only in combination with the appropriate distortion level. For many people not fond of metal music, contemporary distorted guitar tones (Herbst 2017a) may be sufficient to perceive the instrument as heavy. However, this cannot be the one and only rule.

Apart from compositional aspects, the role of production must be considered too. As Mynett (2012, 2013, 2017) showed, heaviness is difficult to achieve in metal productions whilst retaining intelligibility. He argued that elements of the primary domain such as tempo, metre, rhythm, melody and harmony must be brought in line with texture, timbre and location of the secondary domain (Mynett 2013: 40). For instance, layering guitar tracks extends depth by creating a wall of sound, yet the attack can lose definition (Mynett 2013: 106f; Herbst 2017a). Additionally, layering several guitar tracks can make it harder to hear each note within a chord. From a production perspective, more complex harmonic structures reduce tonalness and thus transparency as well. Therefore, heaviness by structure and by production needs to be weighed up. In this respect, the arrangement must be considered too. The more space the guitar covers in the mix, the less is left for other instruments also contributing to heaviness (Eysenberg, Knauf and Reuter 2017). That is why the guitar cannot be dominating. Furthermore, since distortion extends the guitar's frequency range down to 50 Hz in the bass and up to at least 12 kHz in the highs (Herbst 2017a), the instrument competes with all other band instruments even without a greater spectral density of an increased harmonic complexity. These negative effects can be controlled in the mixing and mastering to some extent, but in a live situation, this is much more difficult. Ultimately, the musicians and producers must decide on how to achieve the required heaviness. As Berger (1999: 59) argues, "any element of the musical sound can be heavy if it evokes power or any of the grimmer emotions". Therefore, metal music's subgenres can shape heaviness by different means, which again creates options for genre development.

Methodical limitations

The results of this study are subject to certain limitations. Since only music-affine higher education students were recruited, the sample of the listening test cannot be regarded as representative. Another critical point is that music aesthetics was only considered rudimentary in form of music preferences. Furthermore, guitar playing in authentic musical contexts may differ from the experimental findings. In a live situation or a studio production, the guitar sound is affected by playing techniques, other instruments and sound engineering, all of which influence volume, frequency and tonal composition. Moreover, what in a concert supports the exciting atmosphere might be perceived quite differently elsewhere. Even within a song, repetition changes the perception (Berger 1999: 238).

Conclusion

This study has analysed the interaction between distortion and harmonic structures on the electric guitar. It confirmed distortion's relevance for heaviness from the listener's perspective whilst exploring structural and person-related factors as well. The data demonstrated the concept of sensory consonance to be a suitable model for discussing heaviness and a promising basis for future work. Although the results complied with most research, they still give rise to further questions about heaviness in metal music. What is the intention behind heaviness and who are its recipients? Is it a means of distinction between "true" metalheads, mainstream metalheads and non-metalheads? Should it socially and aurally distinguish between metal music's subgenres as the findings on person-related factors indicate? Or does metal music have to become heavier in the future so as to still stimulate listeners accustomed to heavy sounds? Answering these questions requires further theoretical deliberation and ethnographic research. Subsequent studies could focus on the social experience of heaviness as well as on related areas of perception beyond what has been done in this work.

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