# The Sound of Joy, the Sound of Hardness

## Emotional and metaphorical sound impressions in the light of signal analysis

**1 Audio Feature Extraction**

**2 Timbre Features in Noise**
2.1 Annoying Motorbikes
2.2 Emergency Vehicle Sirens
2.3 Branch-dependent Audio logos

**3 Timbre Features in Music**
3.1 The Sound of Hardness
3.2 The Sound of Joy

**4 Chills - Bigger than Joy**

# The Sound of Joy, the Sound of Hardness

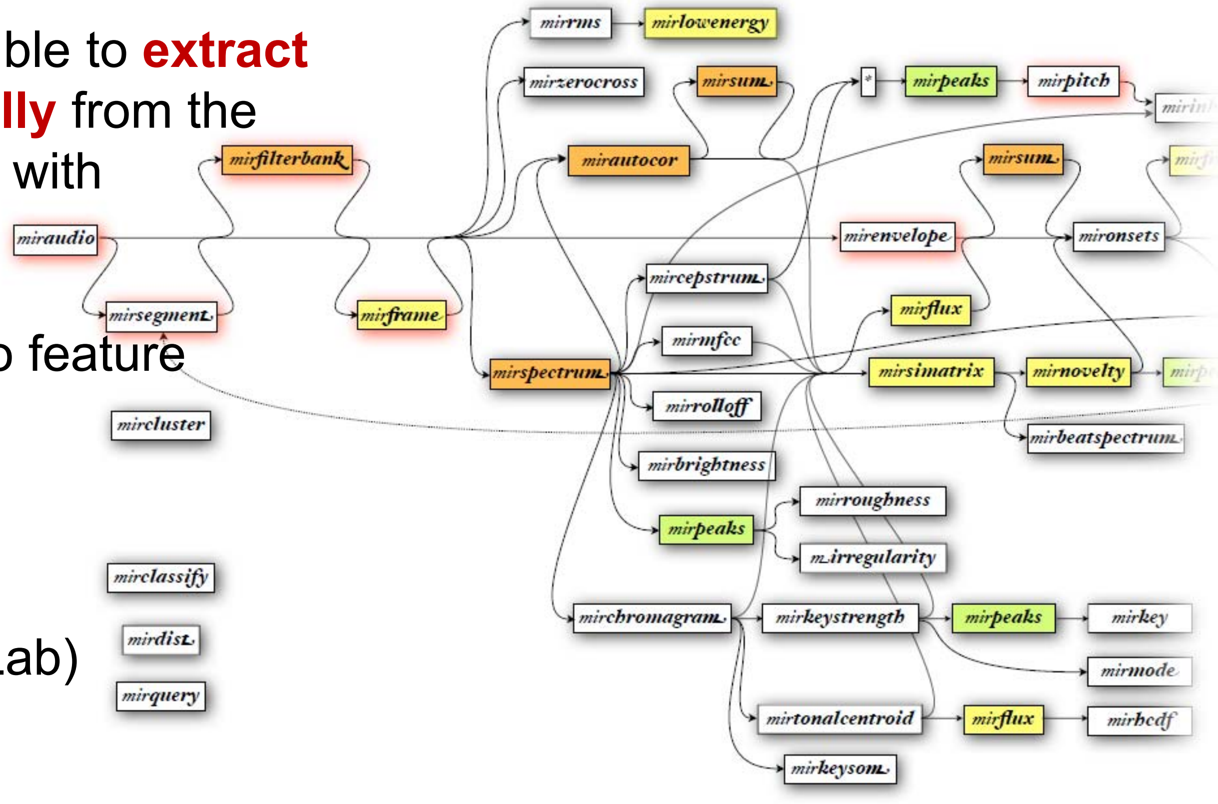
## 1 Audio Feature Extraction

Since about 2000, it is possible to **extract audio features automatically** from the audio file instead of working with annotated metadata.

**Common libraries** for audio feature extraction are e.g.:

- Essentia (for Python)
- Librosa (for Python)
- Timbre Toolbox (for MatLab)
- MIRToolbox (for MatLab)

etc.

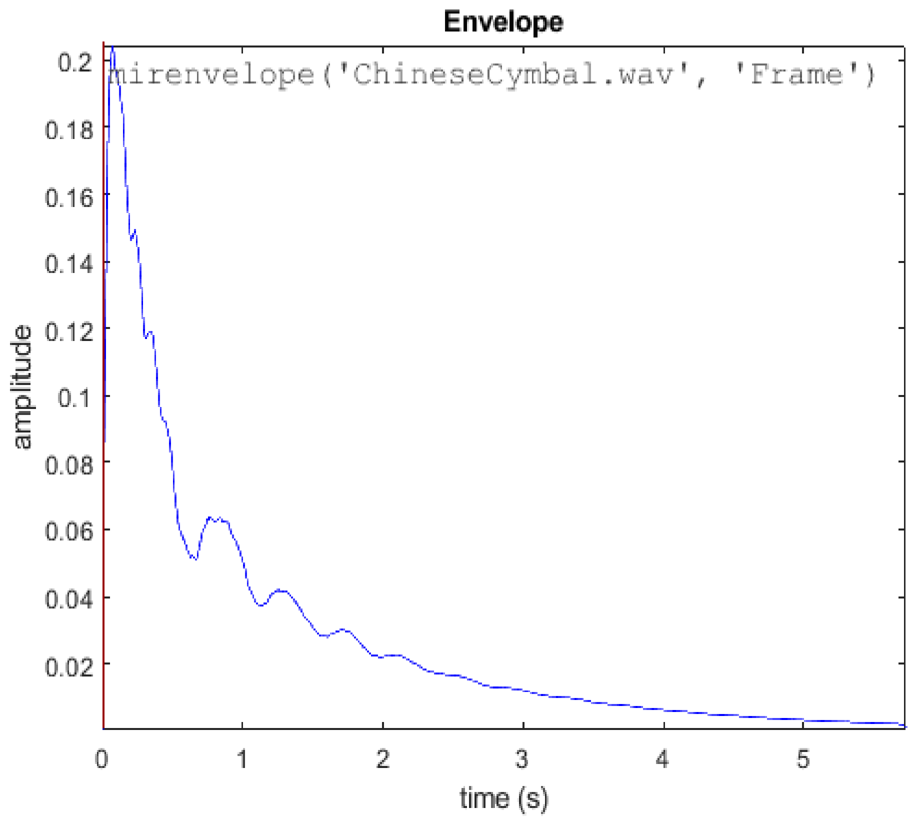



[The manifold possibilities of the Matlab-MIRToolbox (Lartillot, Toiviainen, Eerola 2007)]

# The Sound of Joy, the Sound of Hardness

## 1 Audio Feature Extraction

With the help of these libraries, **timbre features** like brightness, roughness, attack time **can easily be extracted**.

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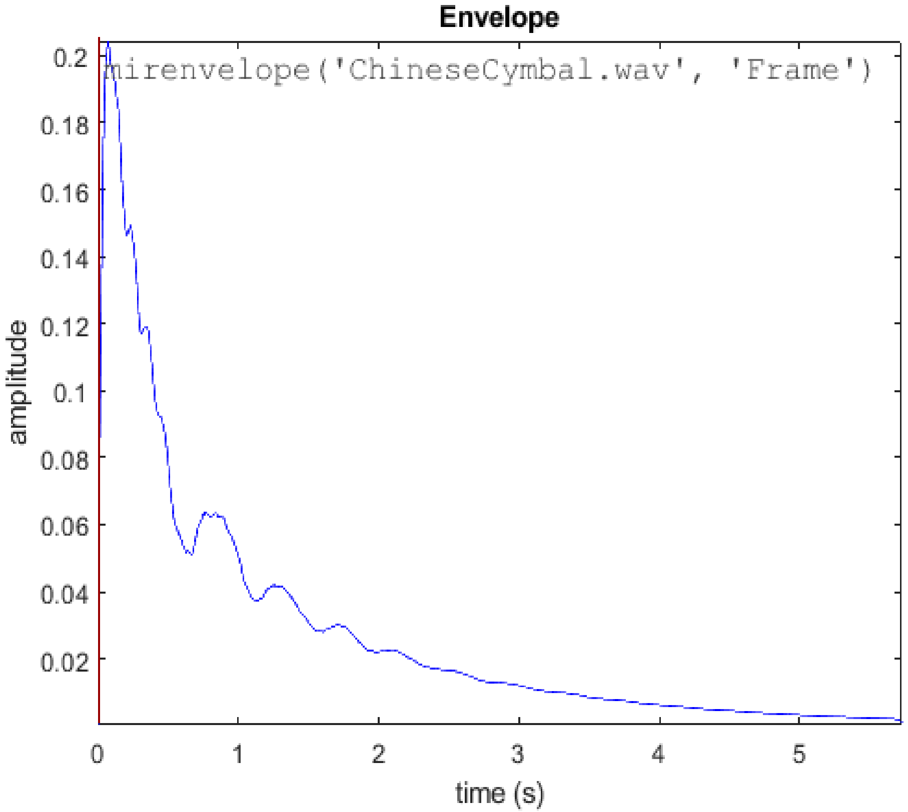


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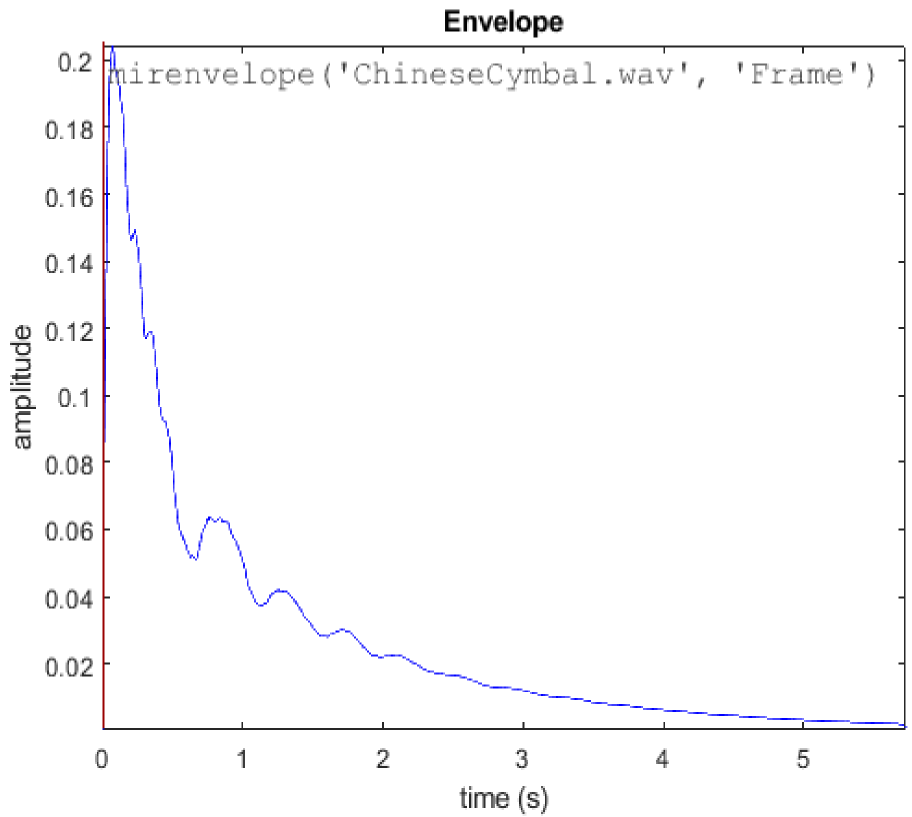
At Vienna Musicology we often use audio feature extraction to determine **human-like meta-descriptors** for noises, sounds and music.

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# The Sound of Joy, the Sound of Hardness

## 2.1 Annoying Motorbikes

Traffic noise (cars, trucks, motorbikes etc.) is usually expressed in **dB**.
In Austria and Germany, **motorcycle noise** should not exceed **71-80 dB** (depending on the engine capacity, measured from a distance of 7,5 m).

Which timbre features are responsible for the sound of a motorbike being perceived as annoying?

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Since the 1990s, psychoacoustic sound parameters have been studied to describe the **annoyance** caused by machine and vehicle noises:

Which timbre features are responsible for the sound of a motorbike being perceived as annoying?

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Annoyance caused by (traffic) noise is mostly characterized by **pitch salience**, **sharpness**, **roughness** and **attack time**.

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# The Sound of Joy, the Sound of Hardness

## 2.1 Annoying Motorbikes

**Question: Which audio features contribute to the perception of Motorbike sounds causing annoyance?**

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25 test subjects rated 60 prototypical motorbike sounds on a **ten-point scale** with regard to their **perceived annoyance** (1 = not annoying, 10 = very annoying).

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From the 60 stimuli, a large number of audio features were determined via **Matlab toolboxes**, and they were tested for correlation with the test persons' perceived annoyance.

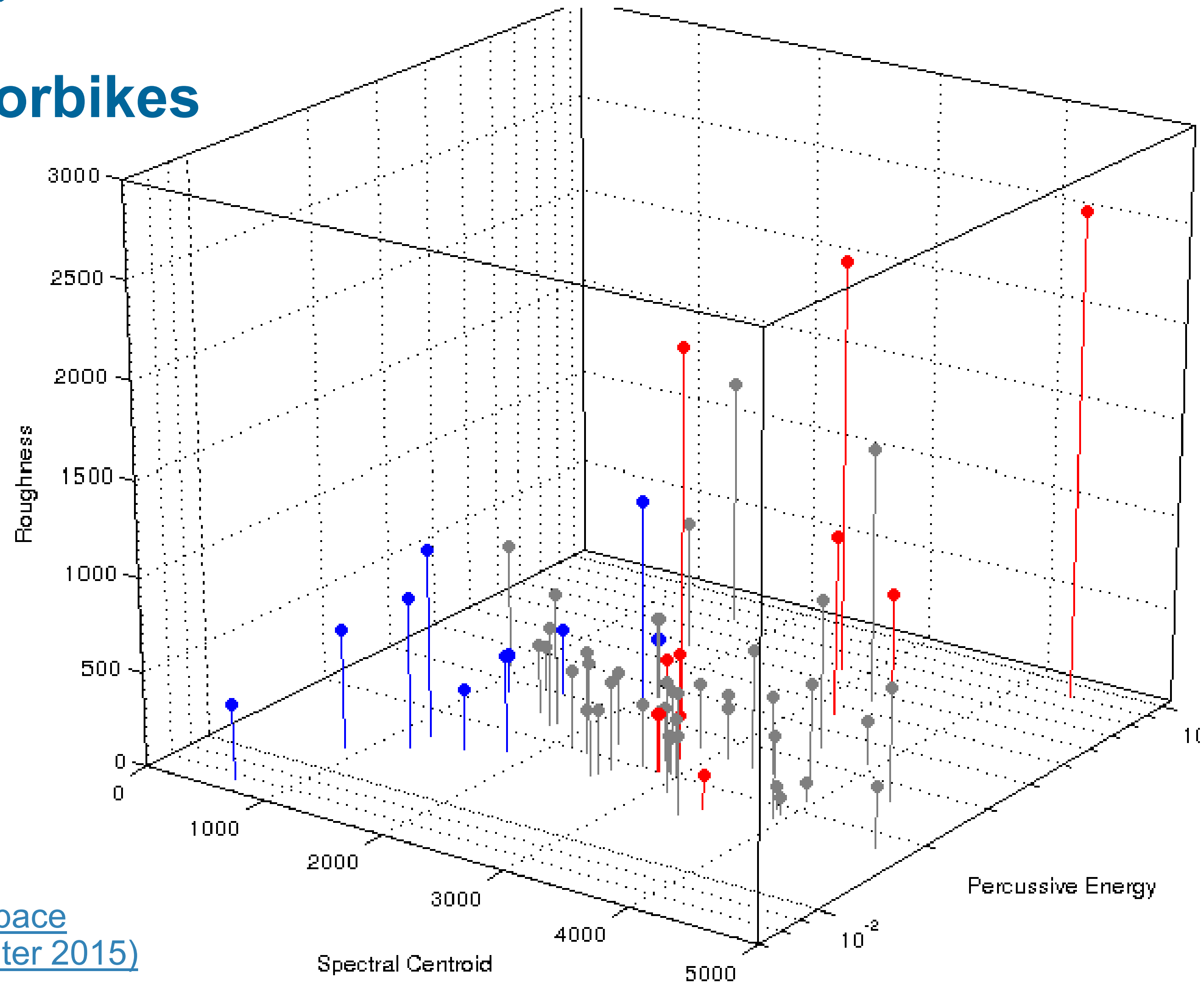
| Timbre feature | r | p |
|---|---|---|
| Spectral centroid | 0,54 | 0,00 |
| Loudness | 0,60 | 0,00 |
| Roughness | 0,46 | 0,00 |
| Harmonic/Percussive Ratio | -0,42 | 0,00 |
| Percussive Energy | 0,53 | 0,00 |
| 2-4 kHz Frequency Band | 0,66 | 0,00 |
| Attack Time | -0,29 | 0,02 |

Timbre features correlating significantly with perceived annoyance

# The Sound of Joy, the Sound of Hardness

## 2.1 Annoying Motorbikes

### Results




- less annoying
- annoying
- most annoying

[Motorbike sounds timbre space (Czedik-Eysenberg, Knauf, Reuter 2015)]

# The Sound of Joy, the Sound of Hardness

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The values of the relevant timbre features of the **10 most annoying** and **10 less annoying sounds** have been decreased / increased to the respectively **opposite groups level**. 28 test subjects rated the perceived annoyance again.

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| Manipulations | Rating | r | p |
|---|---|---|---|
| (most annoying) | 7,11 | 0,64 | |
| Longer attack | 7,06 | 0,67 | 0,70 |
| Lower spectral centroid | **6,56** | **0,49** | **0,04** |
| Lower percussiveness | 7,00 | 0,68 | 0,12 |
| Lower loudness | **5,89** | **0,72** | **0,00** |
| all manipulations | 5,61 | **0,56** | **0,00** |

| Manipulations | Rating | r | p |
|---|---|---|---|
| (least annoying) | 4,75 | 0,69 | |
| shorter attack | **4,99** | **0,66** | **0,00** |
| higher spectral centroid | 4,70 | 0,54 | 0,62 |
| higher percussiveness | **5,40** | **0,73** | **0,00** |
| higher loudness | **6,30** | **0,63** | **0,00** |
| all manipulations | 6,56 | **0,66** | **0,00** |

Result: **Inverting** the relevant timbre features leads to an **inversion** of the perceived annoyance

# The Sound of Joy, the Sound of Hardness

## 2.1 Annoying Motorbikes – Take Home Message

The **annoyance** of Motorbike sounds can be described by the timbre features **Spectral Centroid**, **Loudness**, **Roughness**, **Harmonic / Percussive Ratio**, **Percussive Energy**, **2-4 kHz Frequency Band**, **Attack Time.**

It is possible to categorize their **annoyance** in a 3D timbre feature space with the help of the features/dimensions **Spectral Centroid**, **Roughness**, and **Percussive Energy**.

It is possible to **decrease the annoyance** with an increase of the **attack time** while lowering the values for **spectral centroid**, **percussiveness** and **loudness**.

On the opposite, it is possible to **increase the annoyance** with a decrease of the **attack time** while raising the values for **spectral centroid**, **percussiveness** and **loudness**.

# The Sound of Joy, the Sound of Hardness

## 2.2 Emergency Vehicle Sirens

The aim of an emergency vehicle is to be as **quickly** as possible and **without accidents** at the destination.

Which timbre features are responsible for the perceived assertiveness of emergency vehicle sirens?

# The Sound of Joy, the Sound of Hardness

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Sirens increase the **perceptibility** from a distance, but it is **not possible** to make them **louder** as they already are.
(emergency services have already an increased **risk of hearing damages**, e.g. Johnson et al. 1980, Pepe et al. 1985).

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**Question: Which audio features contribute to the perceived assertiveness of emergency vehicle sirens?**

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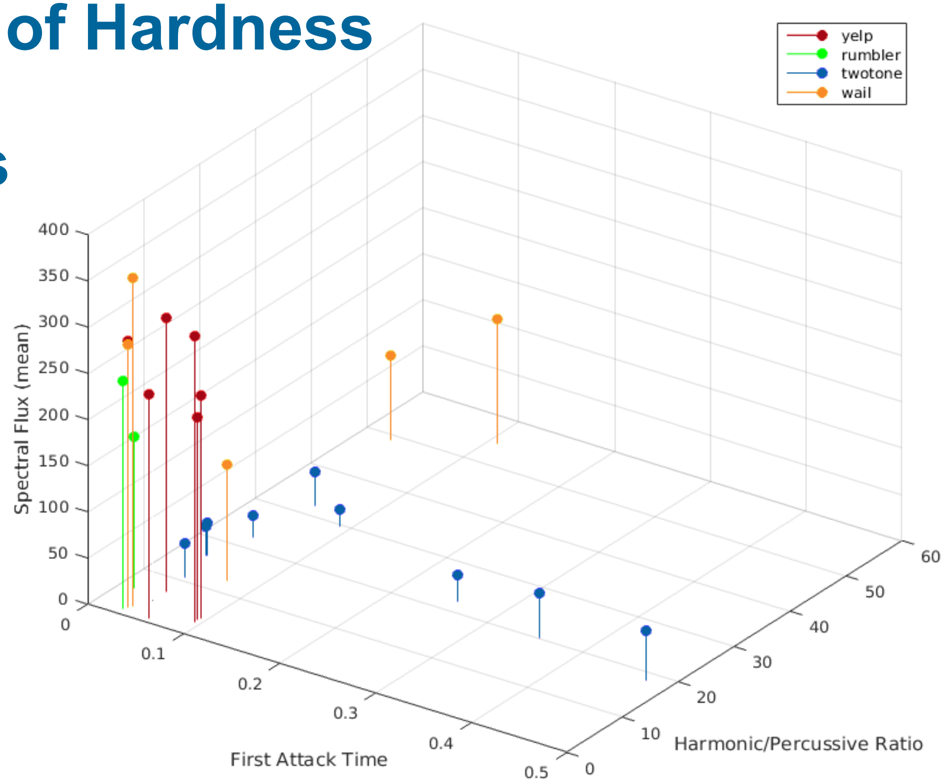
# The Sound of Joy, the Sound of Hardness

## 2.2 Emergency Vehicle Sirens

Based on the classification of **common emergency vehicle siren sounds** (Catchpole & McKeown 2007), the audio features of 22 siren noises have been extracted with the help of Matlab toolboxes:




Timbre feature space of different emergency vehicle siren sounds

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- **Yelps** (continuously trilling)
- **Wails** (in- and decreasing pitch)
- **Hi-Lo** (two-tone sequences)
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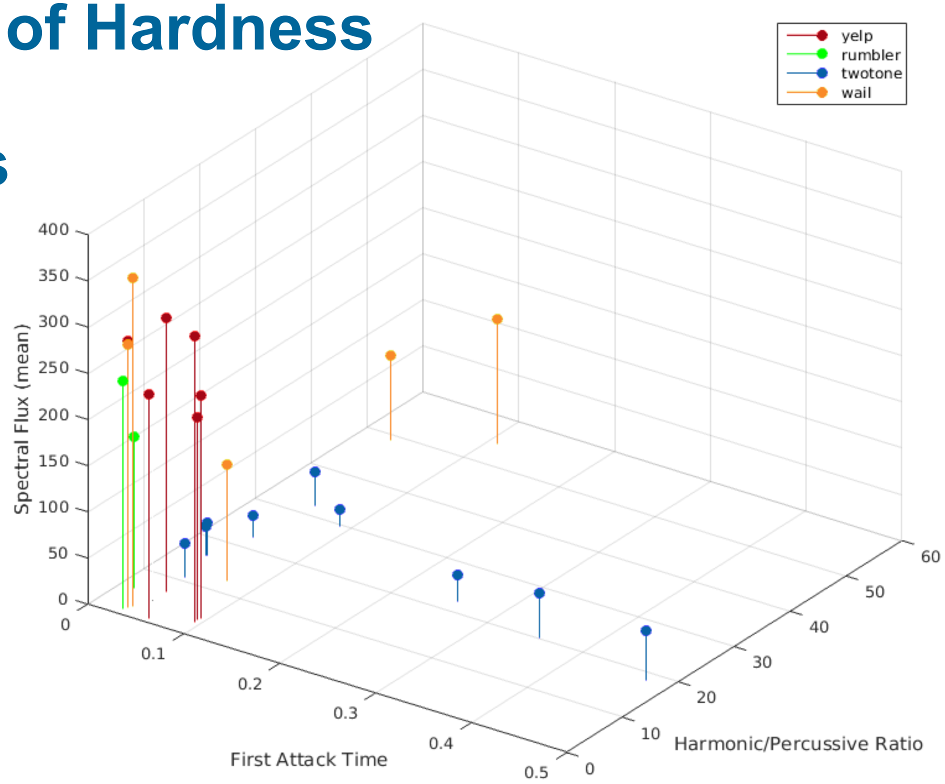


[Timbre feature space of different emergency vehicle siren sounds]

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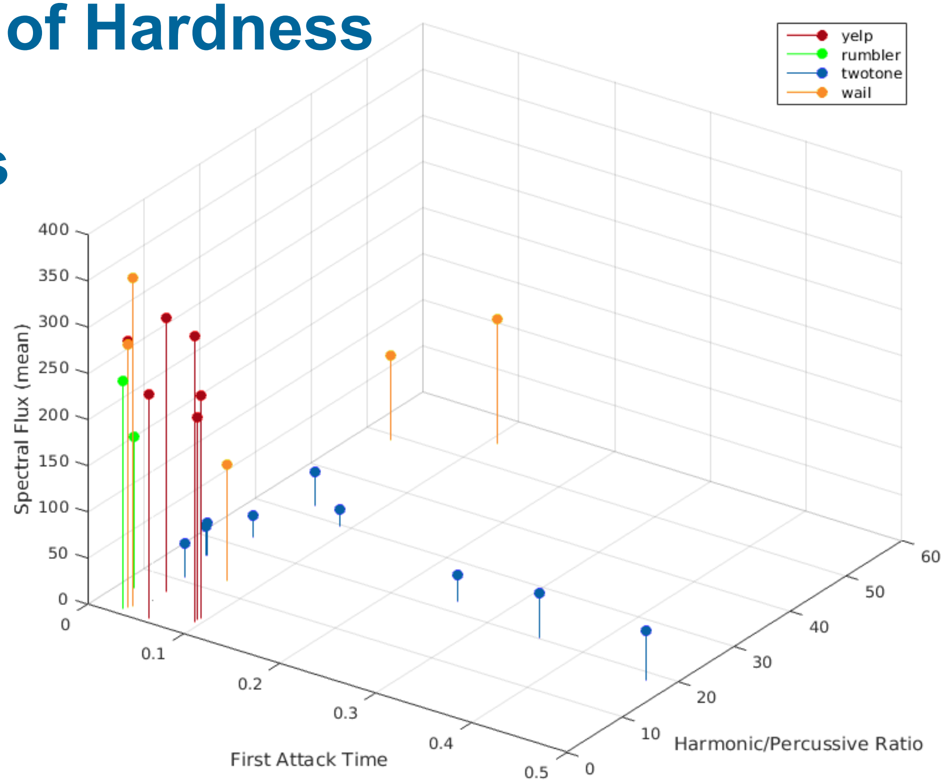


[Timbre feature space of different emergency vehicle siren sounds]

According to the audio feature analysis, the various warning signals can be displayed in a **3D timbre feature space** using **First Attack Time**, **Harmonic / Percussive Ratio** and **Spectral Flux**.

# The Sound of Joy, the Sound of Hardness

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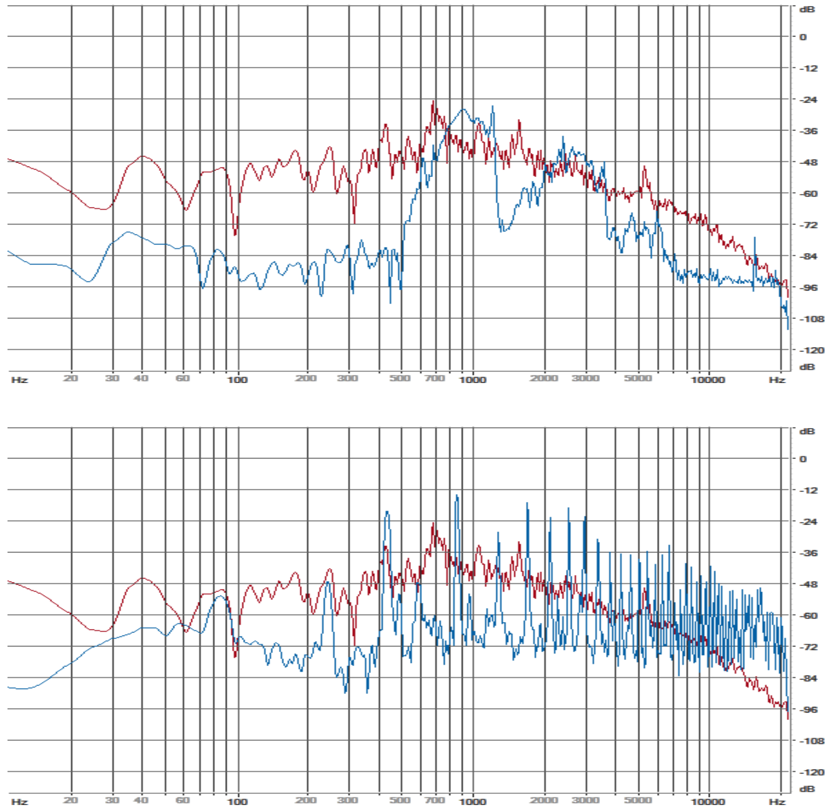
In a second step, the siren sounds have been **embedded into typical acoustic environments** (Urban Park, City Traffic and Loud Crowd) with the help of the software AudioEase Speakerphone.




Siren sounds (blue average Spectrum) masked by a loud crowd (red average spectrum).
top: Yelp-Signal (almost inaudible),
bottom: Hi-Lo-Signal (very well inaudible)

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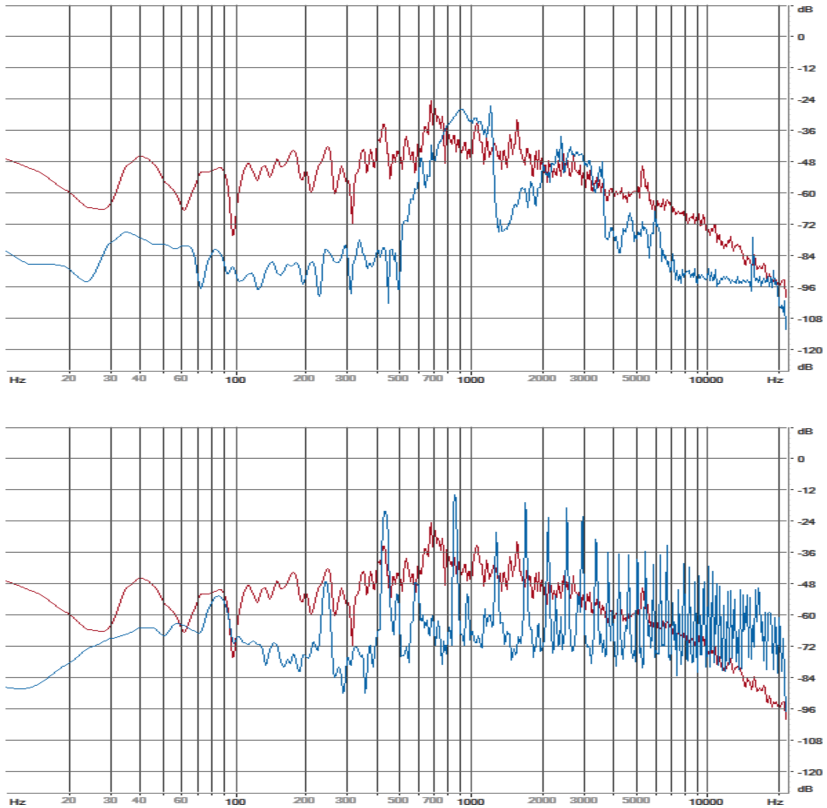
- to compare their **perceptibility** under **equal everyday masking conditions**
- to estimate the **assertiveness** based on the **amplitudes** (blue) above the **masking curve** (red).

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# The Sound of Joy, the Sound of Hardness

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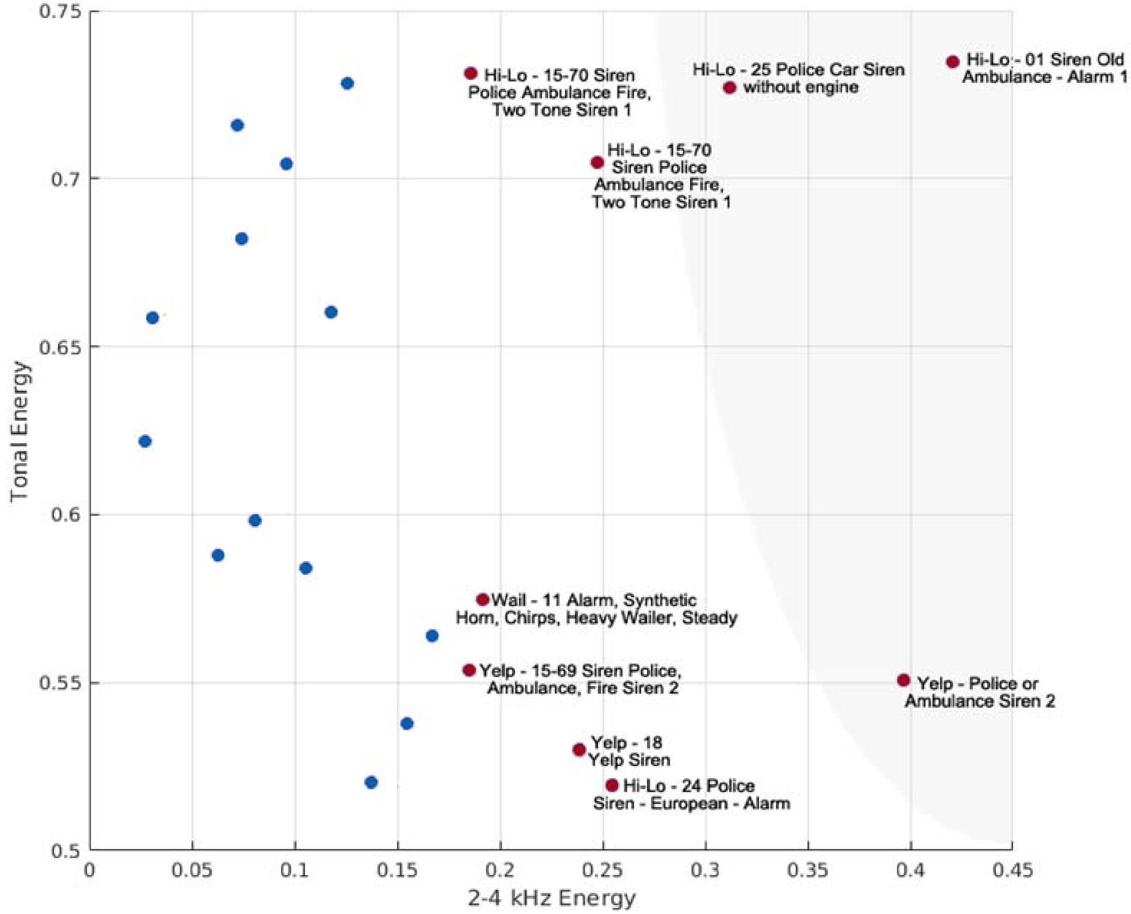
**Very well perceptible** siren sounds in loud environments turned out to have **high values** in the meta timbre descriptor **unpleasantness** = a combination of the timbre features **tonal energy** and strong amplitudes in **2-4 kHz frequency band**
(Czedik-Eysenberg 2016, p. 38ff.).




[tonal energy and 2-4 kHz energy frequency band for the determination of the assertiveness of emergency vehicle sirens]

# The Sound of Joy, the Sound of Hardness

## 2.2 Emergency Vehicle Sirens – Take Home Message

Emergency vehicle siren sounds can be **classified** in a 3D timbre feature space with the help of the features **First Attack Time**, **Harmonic/Percussive Ratio** and **Spectral Flux.**

Under the **same loudness conditions** siren sounds with **high values** in the features **tonal energy** and strong amplitudes in **2-4 kHz frequency band** = can be summarized in the meta-descriptor **unpleasantness**.

# The Sound of Joy, the Sound of Hardness

## 2.3 Branch-dependent Audio logos

Audio logos are **short memorable signature tunes**, which should increase the **recognition value** of a brand or product.


Intro to CCTV News as a typical Audio logo

# The Sound of Joy, the Sound of Hardness

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Audio logos are **short memorable signature tunes**, which should increase the **recognition value** of a brand or product.

In a number of studies audio logos have already been examined concerning their **melodic comprehensibility**, their **impact in cross modal perception**, their **noticeability** in difficult auditory environments etc. pp.
(North et al. 2004; Spence & Driver 2004; Allan 2007; Bronner & Hirt 2007; Anzenbacher 2012; Anzenbacher, Reuter & Oehler 2013; Langeveld et al. 2013).


Intro to CCTV News as a typical Audio logo

# The Sound of Joy, the Sound of Hardness

## 2.3 Branch-dependent Audio logos

**Questions:**

**- Which instruments are most commonly used in audio logos and in which manner is voice/text included?**

**- Are there certain acoustic attributes, which are especially peculiar to the audio logos of certain industrial branches?**


[Intro to CCTV News as a typical Audio logo]

# The Sound of Joy, the Sound of Hardness

## 2.3 Branch-dependent Audio logos

In a study with **364 audio logos** from different industrial sectors their **audio features** have been investigated via a combination of **Matlab/MIRtoolbox** and **musicological analysis**.


Intro to CCTV News as a typical Audio logo

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They were examined for **timbre features**, **segment** and **contour properties** as well as for occurrences of **voice** and/or **specific instruments**.


Intro to CCTV News as a typical Audio logo

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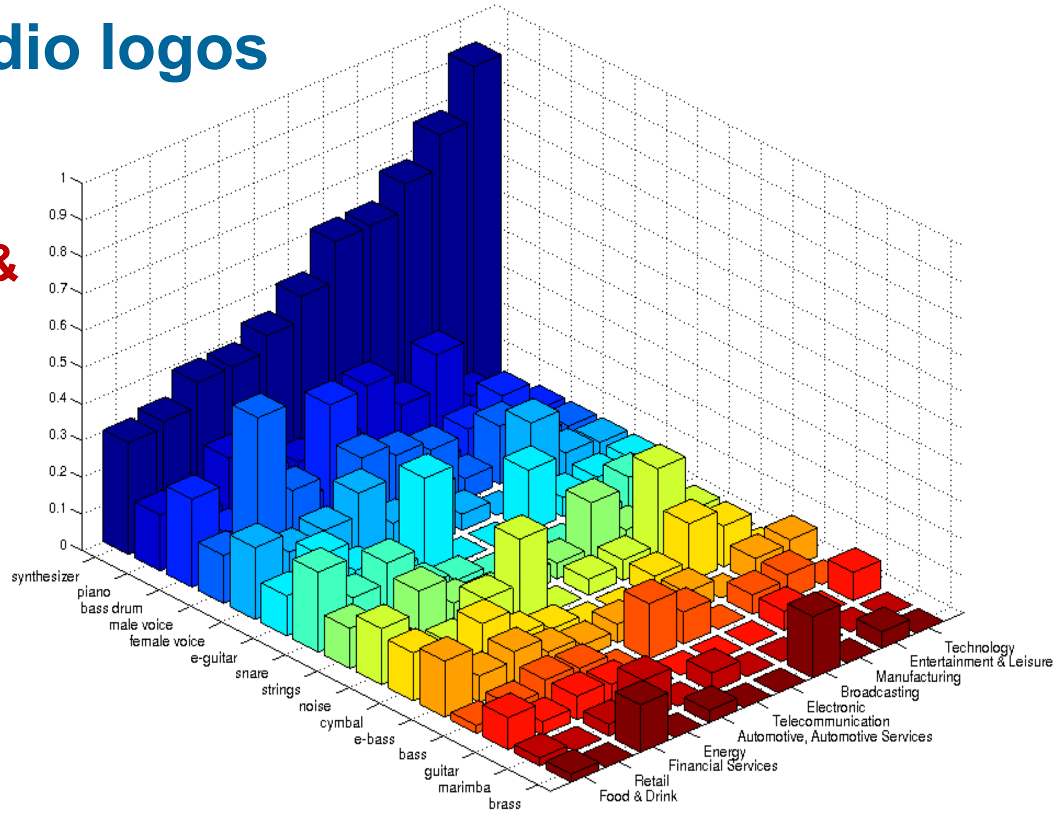
The audio logos were compared with each other in terms of their individual **industrial branch** by means of an ANOVA and Tukey post-hoc analysis.


Intro to CCTV News as a typical Audio logo

# The Sound of Joy, the Sound of Hardness

## 2.3 Branch-dependent Audio logos

Audio logos of technology-driven branches like “**technology**”, “**manufacturing**”, “**entertainment & leisure**”, “**electronic**” and “**broadcasting**” are mostly characterized by **synthetic** sounds.




Typical branch-dependent instrumentation of audio logos
(Czedik-Eysenberg, Anzenbacher, Reuter, Oehler 2014)

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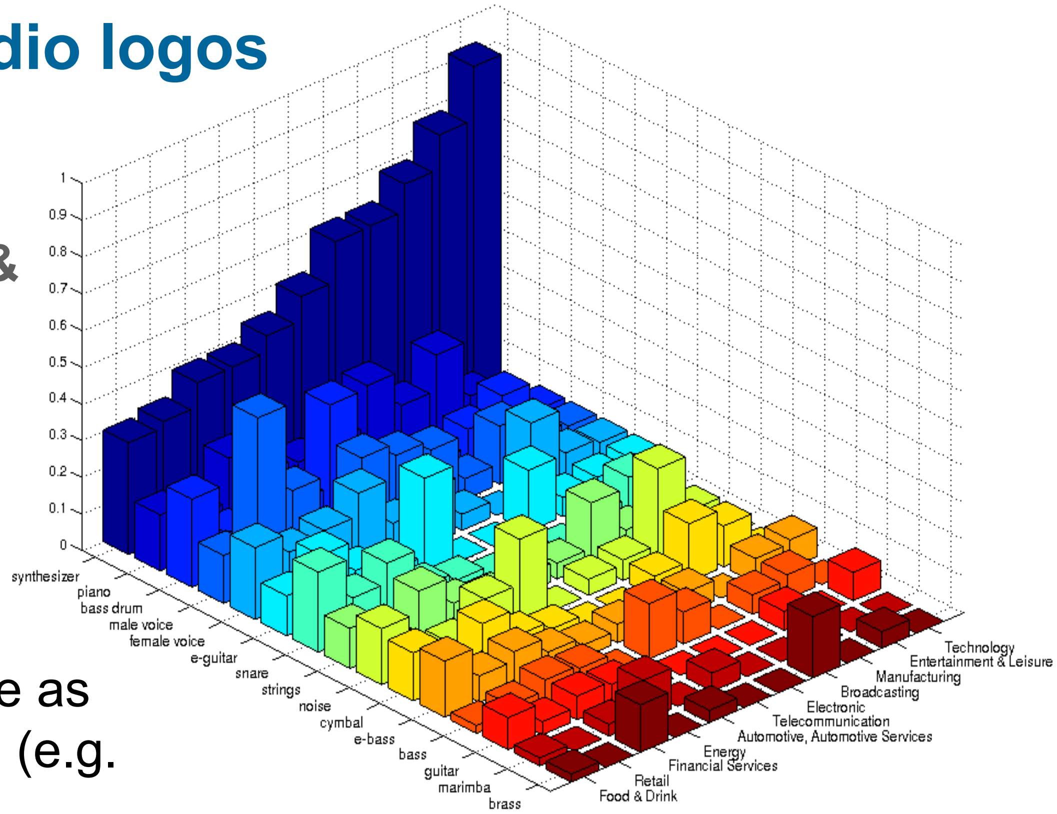


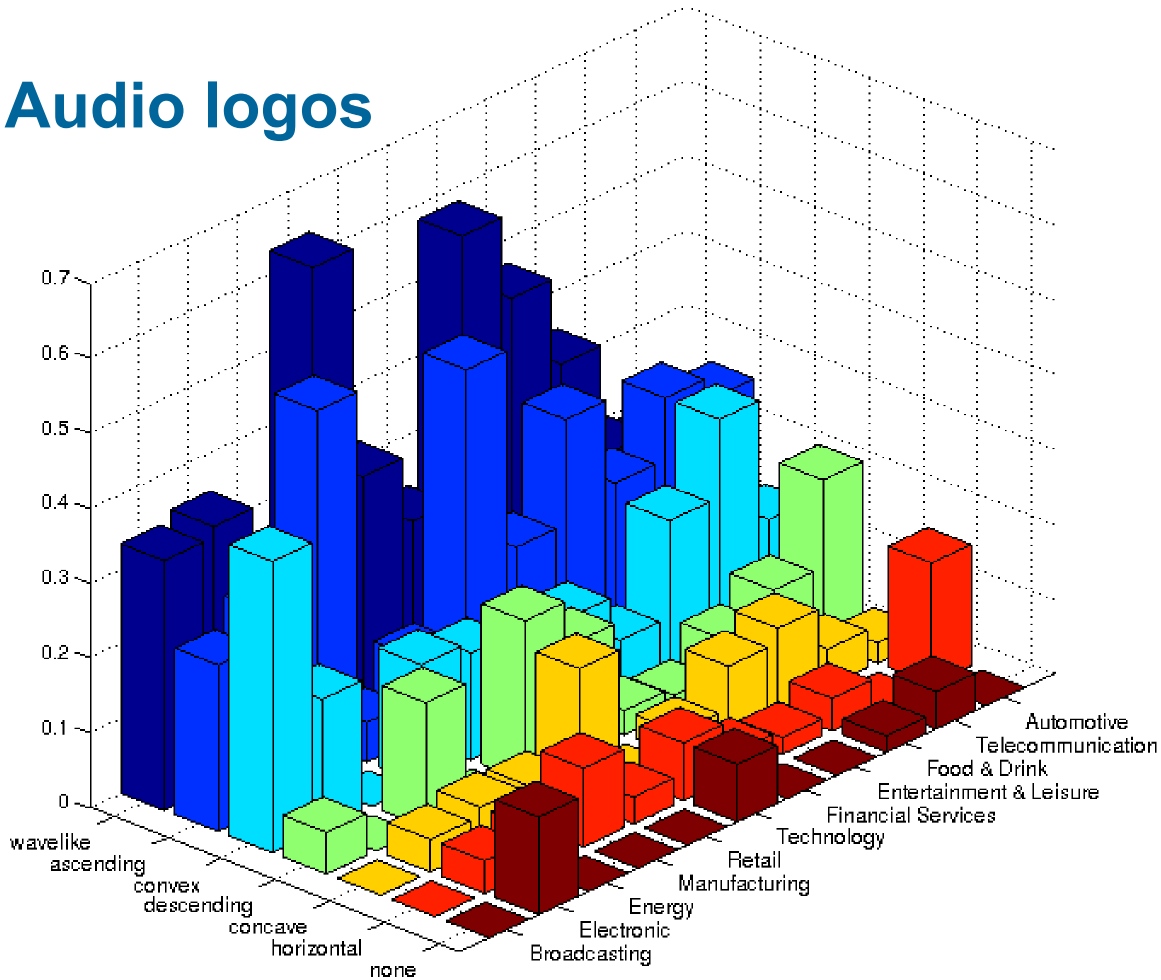

**E-guitar** and **male voice** are common sounds of the **retail** and **automotive** branch. In the latter one as well as in **"manufacturing" noises** (e.g. motor/engine noise) are also very noticeable. **Brass instruments** are often heard in "**broadcasting**" and "**financial services**" audio logos.

Typical branch-dependent instrumentation of audio logos
(Czedik-Eysenberg, Anzenbacher, Reuter, Oehler 2014)

# The Sound of Joy, the Sound of Hardness

## 2.3 Branch-dependent Audio logos

With respect to the **melodic contour** of an audio logo, mostly **wavelike** (especially "**manufacturing**" and "**financial services**") and **ascending** structures (particularly "**energy**" and "**technology**") can be found.




Typical melodic contours of audio logos dependent of the branch
(Czedik-Eysenberg, Anzenbacher, Reuter, Oehler 2014)

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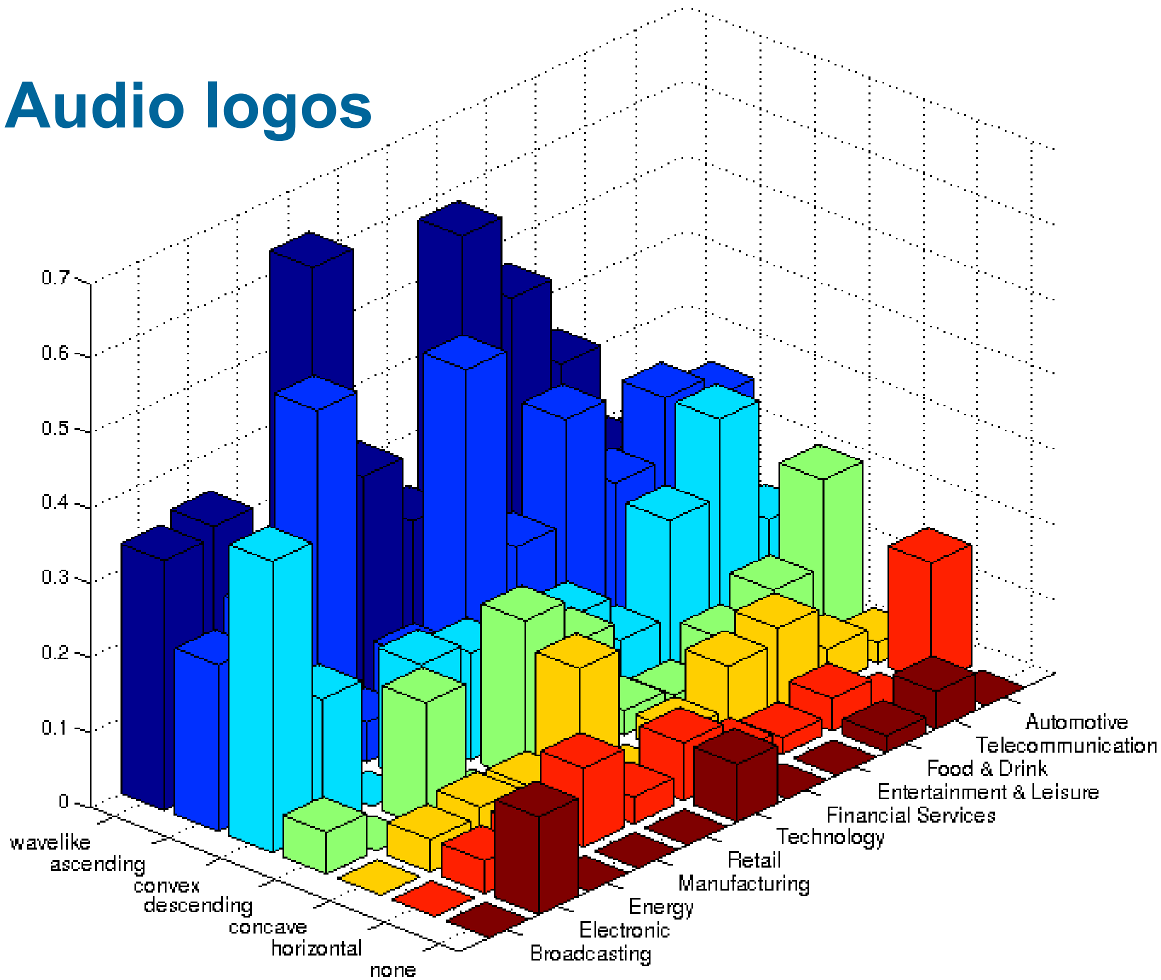
**Convex** structures seem to be typical for "**broadcasting**" and "**telecommunication**".

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# The Sound of Joy, the Sound of Hardness

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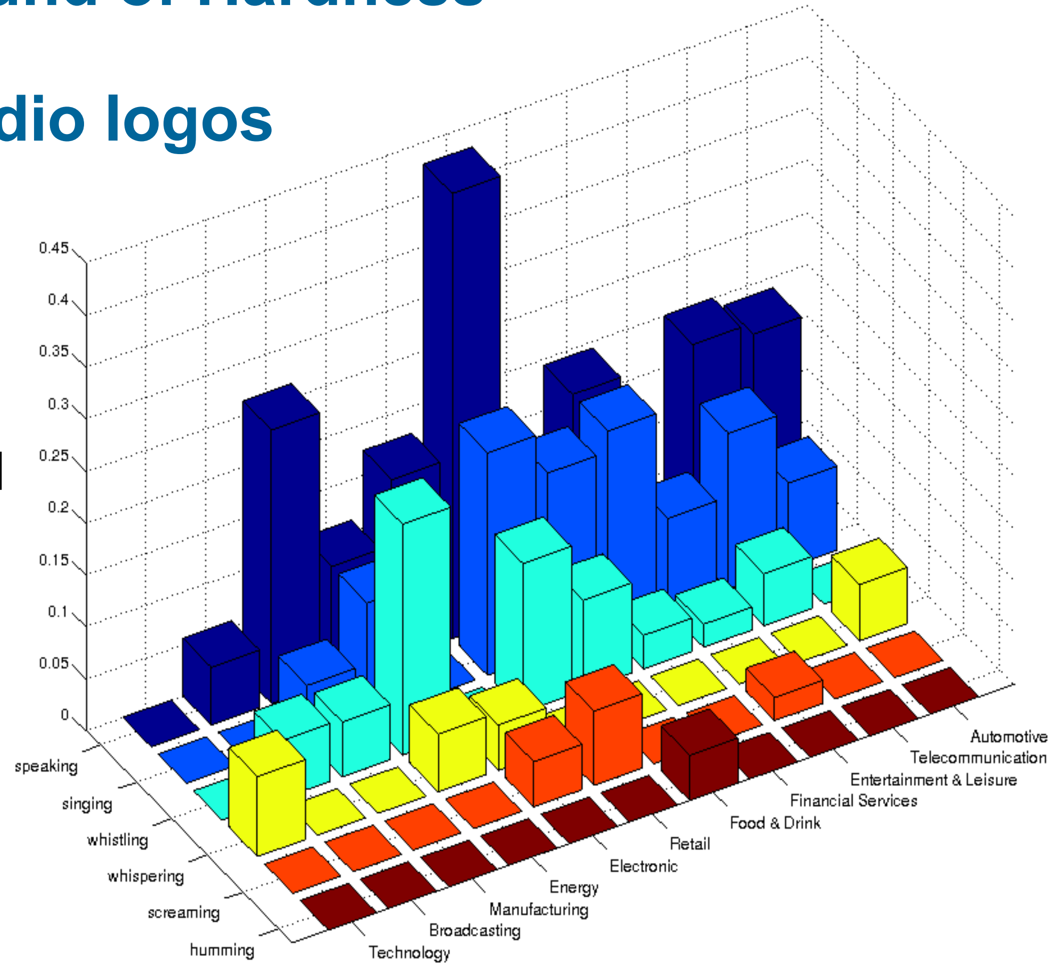
Audio logos of the **technology**-driven industries mostly do **without** the use of **human voice**, while in “**retail**” and **service-orientated** branches **singing** and **speaking** is the normal case.




The use of the voice in audio logos dependent of the branch (Czedik-Eysenberg, Anzenbacher, Reuter, Oehler 2014)

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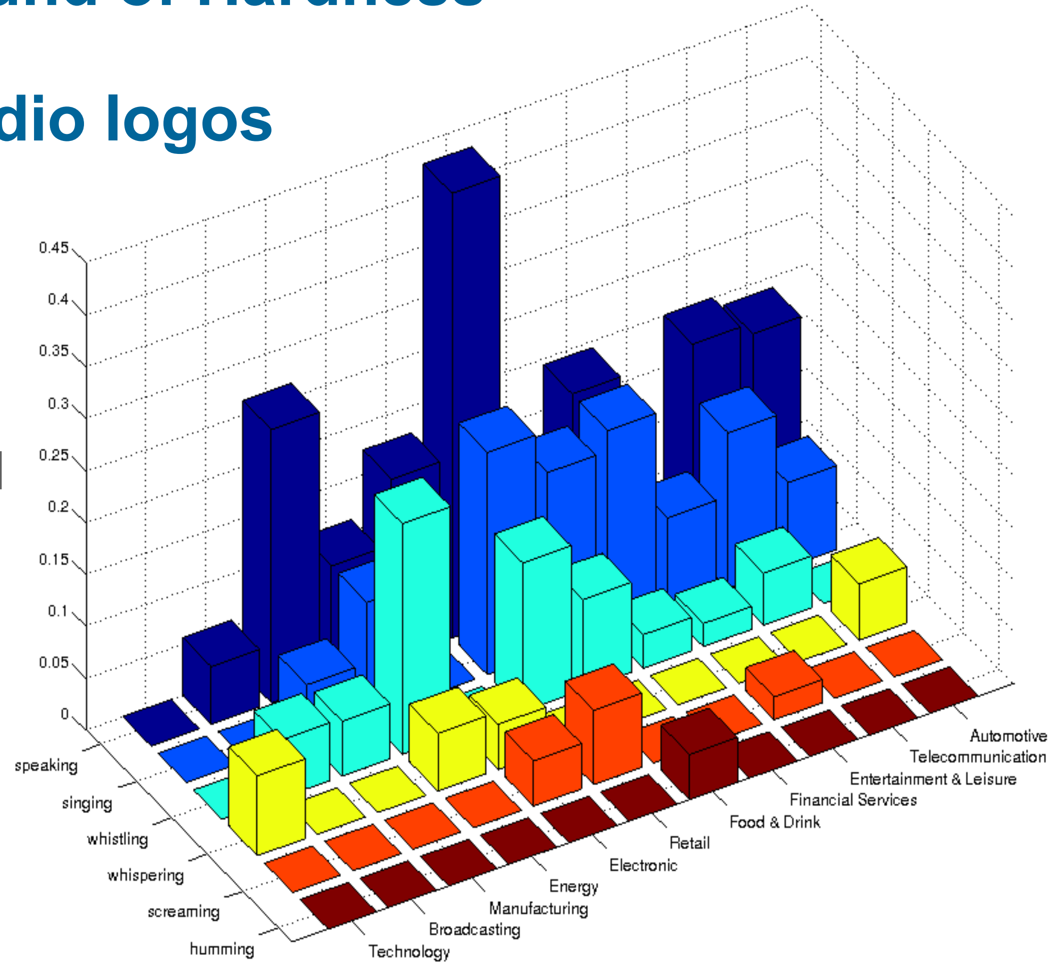
Apart from **spoken** and **sung** slogans (e.g. "**food & drink**"), **whistling** (e.g. "**energy**"), **whispering** (e.g. "**automotive**") and **humming** (e.g. "**food & drink**") is also typical for certain branches in audio logos.




The use of the voice in audio logos dependent of the branch
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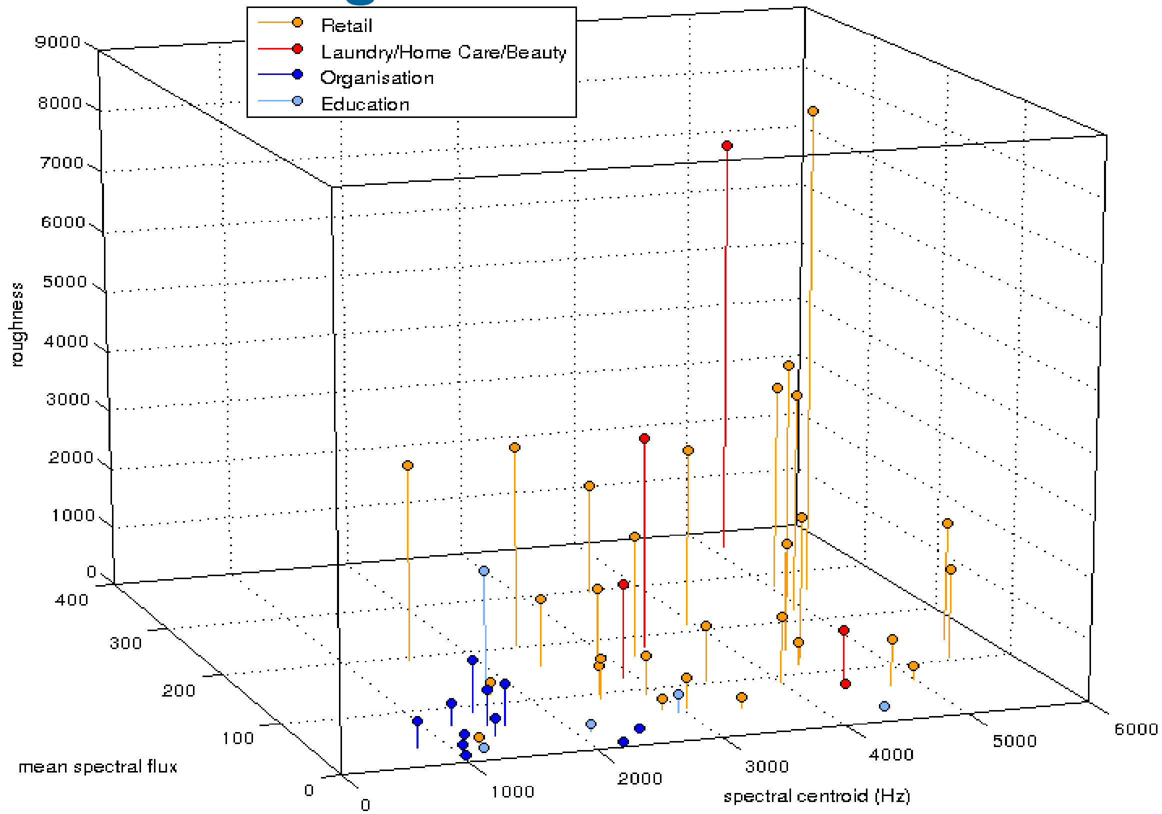
# The Sound of Joy, the Sound of Hardness

## 2.3 Branch-dependent Audio logos

Audio logos of the branches "**laundry/home care/beauty**“ and "**retail**“ are more or less **similar** in their acoustical properties (spectral centroid, spectral flux, roughness), while they **differ** significantly from the audio logos of “**organisation**” and “**education**”.

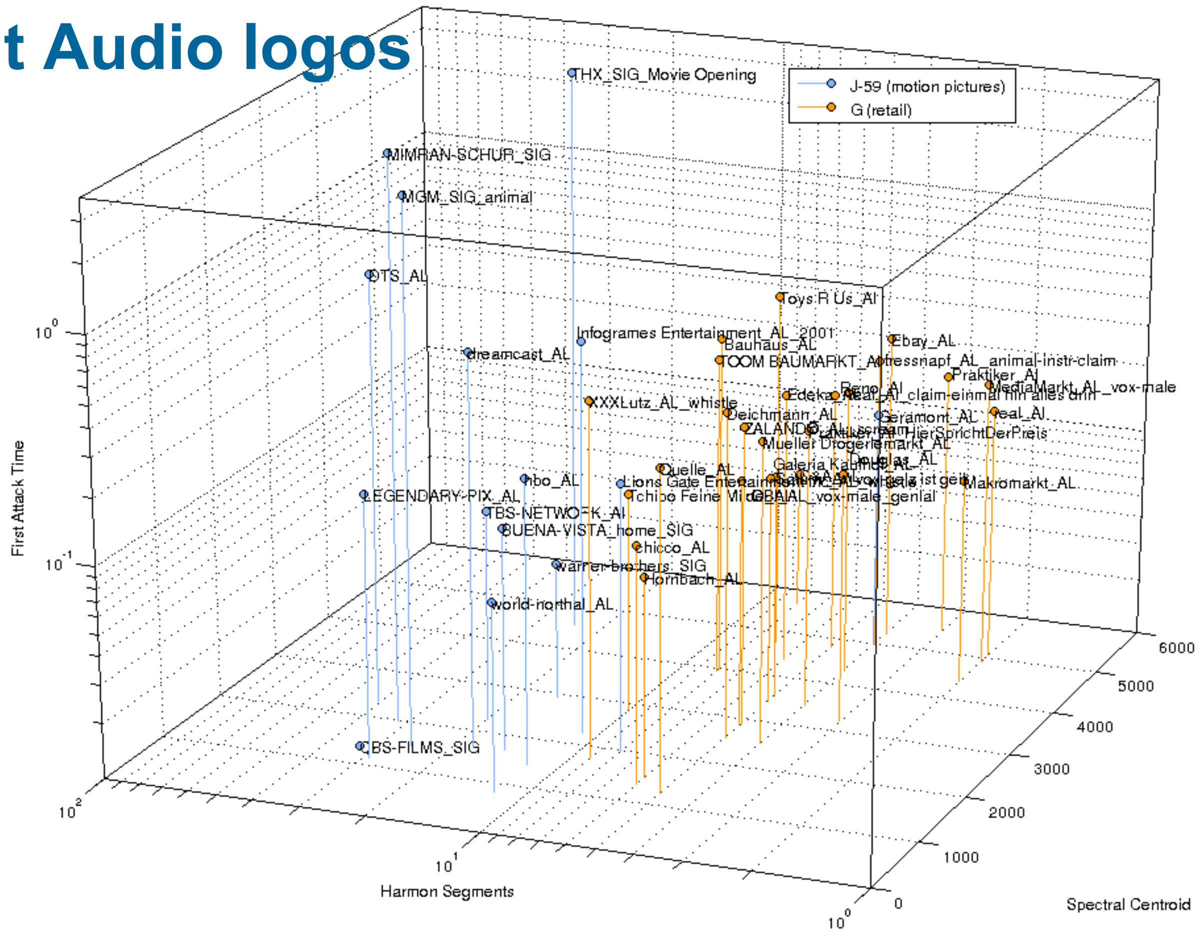



Branch-dependent timbre features in the audio logos of retail and laundry/home care/beauty vs. organization and education (Czedik-Eysenberg, Anzenbacher, Reuter, Oehler 2014)

# The Sound of Joy, the Sound of Hardness

## 2.3 Branch-dependent Audio logos

Audio logos of the branch "**retail**" can be **distinguish** from the audio logos of **motion picture companies** by the timbre features spectral centroid, number of harmonic segments, and attack time.

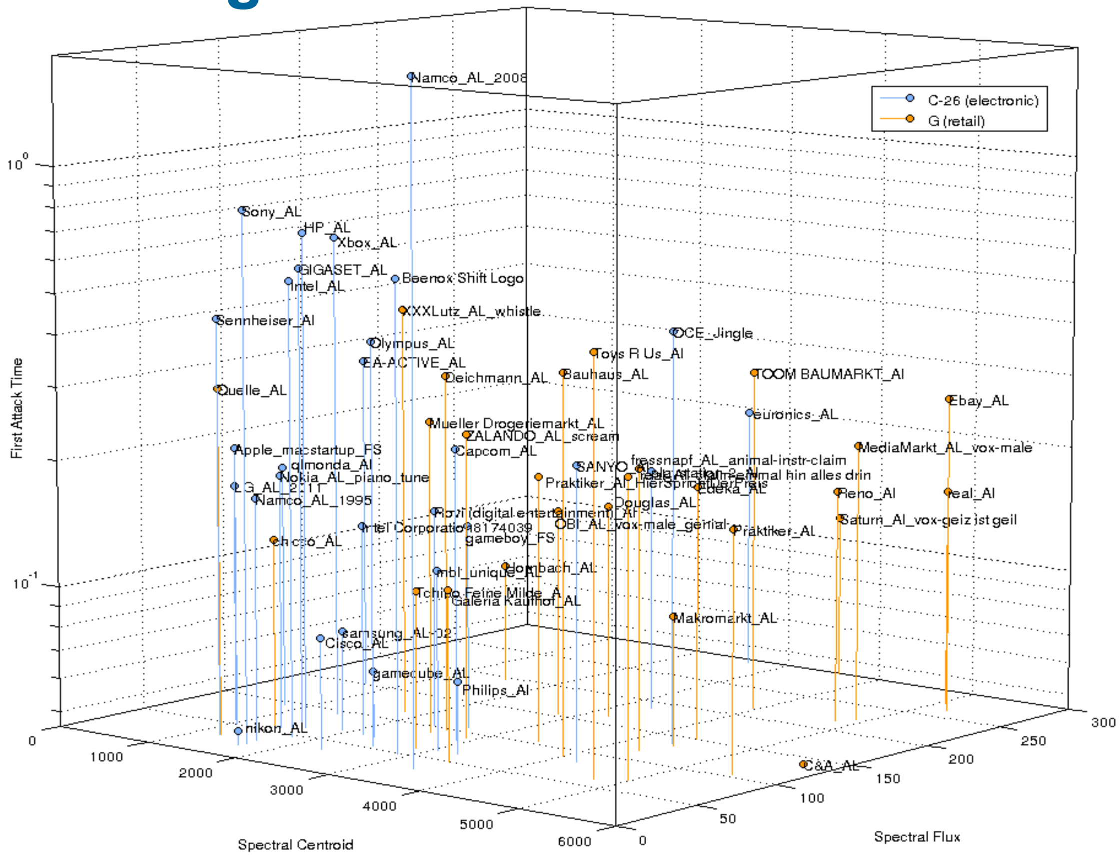



[Branch-dependent timbre features in the audio logos of retail vs. motion pictures (Anzenbacher, Czedik-Eysenberg, Reuter, Oehler 2016)]

# The Sound of Joy, the Sound of Hardness

## 2.3 Branch-dependent Audio logos

Audio logos of the branch "**retail**“ can be **distinguish** from the audio logos of **electronic companies** by the timbre features spectral centroid, spectral flux, and attack time.




[Branch-dependent timbre features in the audio logos of retail vs. electronic (Anzenbacher, Czedik-Eysenberg, Reuter, Oehler 2016)]

# The Sound of Joy, the Sound of Hardness

## 2.3 Branch-dependent Audio logos – Take Home Message I

Audio logos are **short memorable signature tunes**, which should increase the **recognition value** of a brand or product.

| **Branch** | **Instruments/sounds** | **Melodic contours** | **Use of Voice** |
|---|---|---|---|
| **Technology/Energy** | mostly synthetic timbres | ascending | none (whistling) |
| **Retail** | mostly E-guitar | wavelike, descending | speaking (mostly male) |
| **Automotive** | mostly E-guitar, motor engine sounds | wavelike, descending, horizontal | speaking, singing, whispering |
| **Broadcasting/TV** | mostly brass instruments | convex | speaking, whistling |
| **Financial service** | mostly brass instruments | wavelike | speaking, singing |
| **Food & Drink** | less synthetic instruments | wavelike, ascending | speaking, singing, humming |

# The Sound of Joy, the Sound of Hardness

## 2.3 Branch-dependent Audio logos – Take Home Message II

**Retail** audio logos can be separated automatically from **organization / education** audio logos by the timbre features **spectral centroid**, **roughness**, and **spectral flux**.

**Retail** audio logos can be separated automatically from **motion picture** audio logos by the timbre features **spectral centroid**, **attack time**, and **number of harmonic segments**.

**Retail** audio logos can be separated automatically from **electronic companies** audio logos by the timbre features **spectral centroid**, **attack time**, and **spectral flux**.

# The Sound of Joy, the Sound of Hardness

## 3.1 The Sound of Hardness

‘**Hardness**’ is often considered a distinctive feature of **(heavy) metal music**.

Which timbre features are responsible for the perceived hardness in rock, pop and heavy metal music?

# The Sound of Joy, the Sound of Hardness

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**But what does hardness sounds like?**

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# The Sound of Joy, the Sound of Hardness

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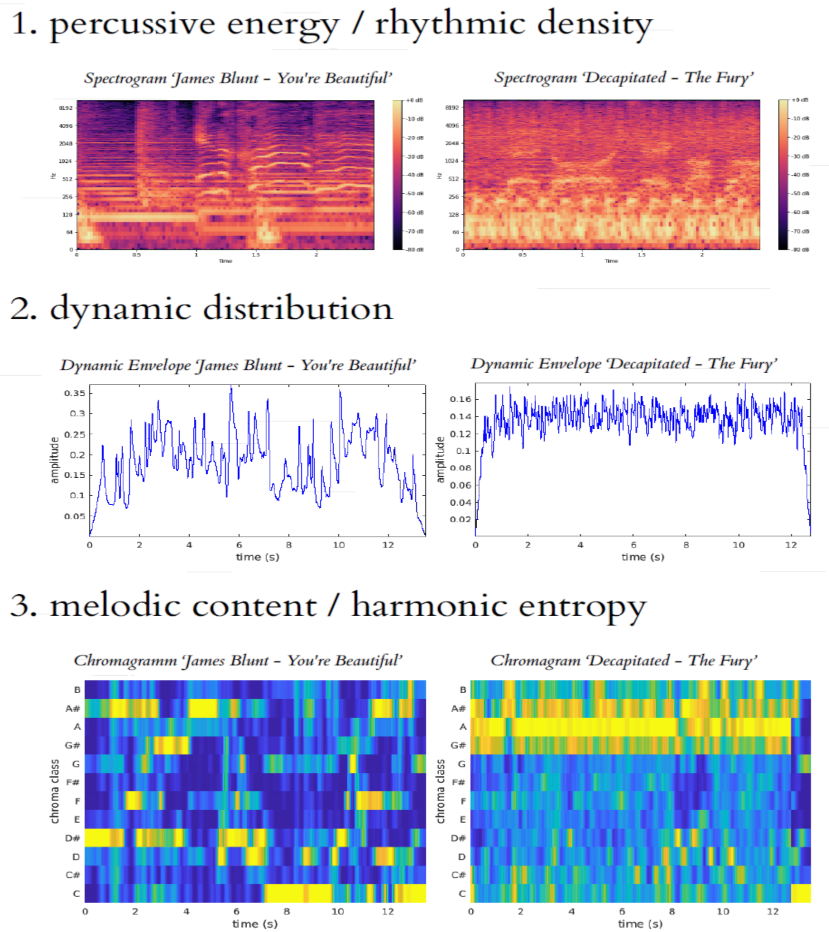
Considering Bonferroni correction, **65 significant feature correlations** were found for the concept of 'hardness'.




Main timbre features causing the subjective impression of timbral hardness (left: soft, right: hard) (Czedik-Eysenberg, Reuter, Knauf 2018)

# The Sound of Joy, the Sound of Hardness

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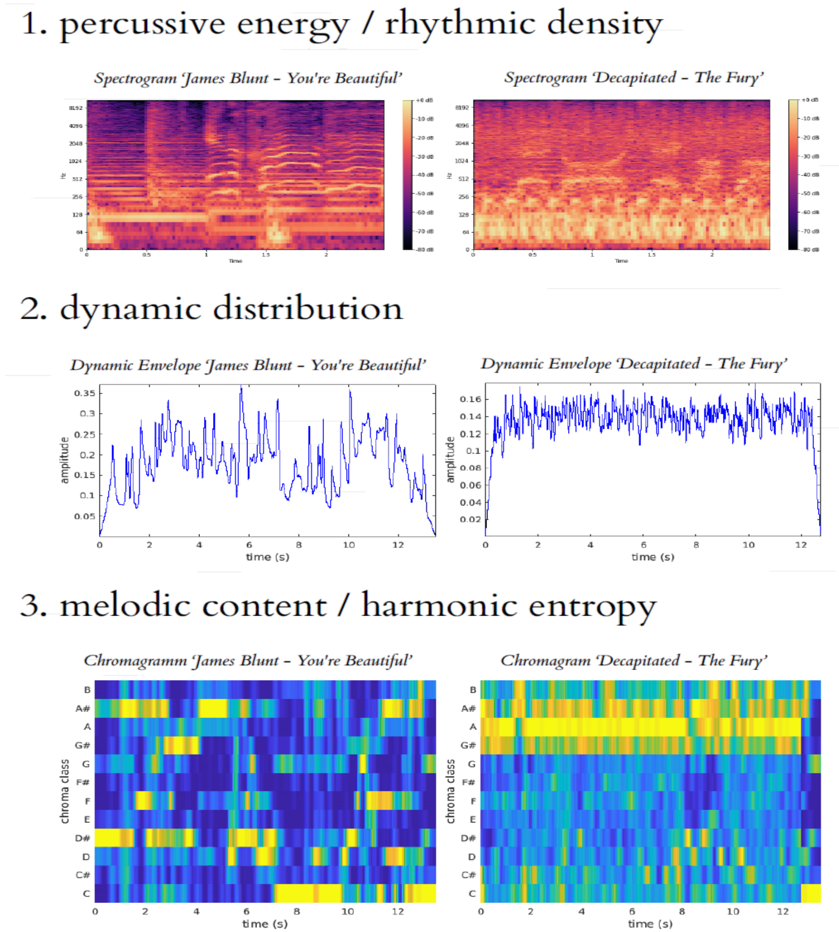
The characterizing attributes of ‘hardness’ include **high tempo** and **sound density**, less focus on clear melodic lines than **noise-like** sounds and especially the occurrence of strong **percussive** components.

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# The Sound of Joy, the Sound of Hardness

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To select an **optimal feature set,** different methods have been used to **reduce the dimensionality**
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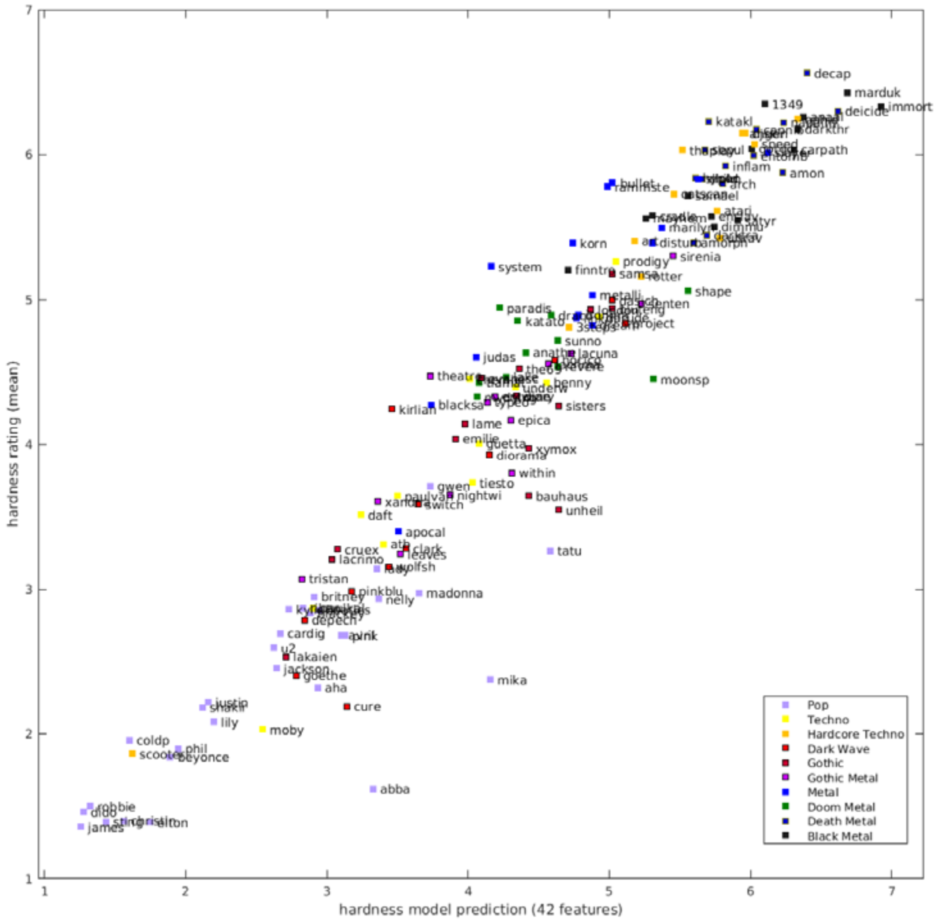
Each under 5-fold cross-validation.




Hardness regression model
(Czedik-Eysenberg, Knauf, Reuter 2017)

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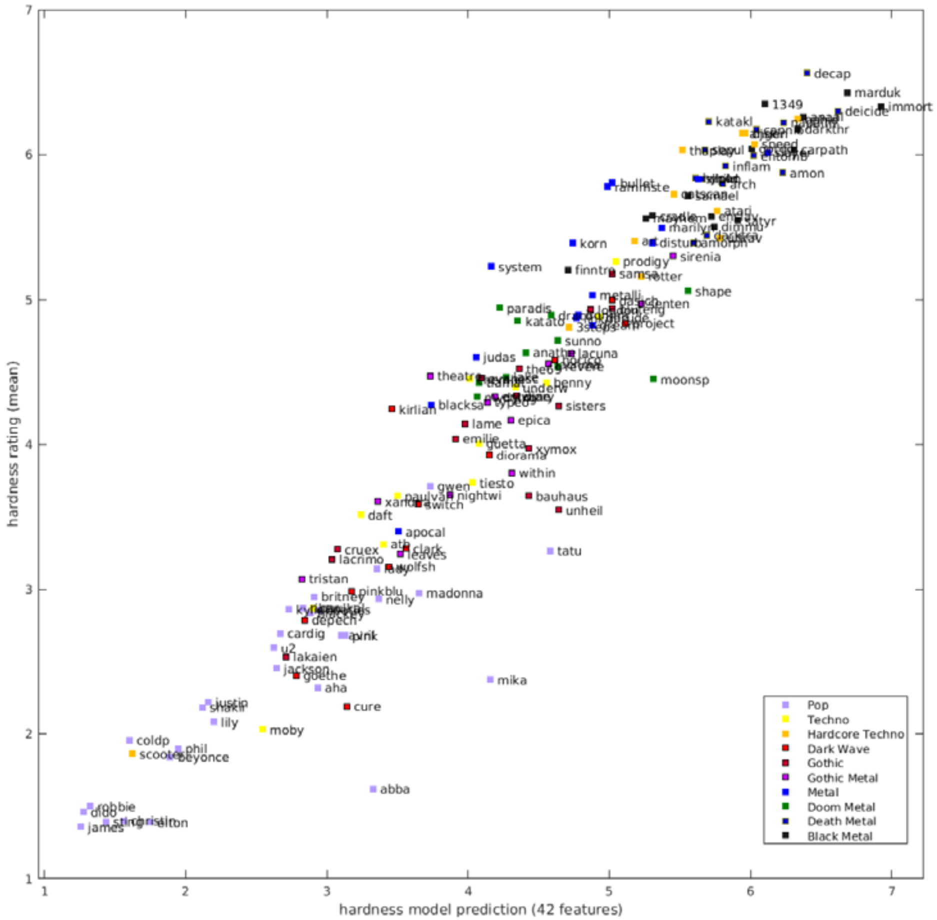
Finally, **regression models** have been developed, also each under 5-fold cross-validation.

| Regression model | RMSE | $r^2$ | MSE | MAE | r |
|---|---|---|---|---|---|
| LASSO (18 feat.) | 0,62 | 0,80 | 0,39 | 0,47 | 0,925 |
| SFS (24 features) | 0,57 | 0,84 | 0,33 | 0,44 | 0,957 |
| SFS (top 5 feat.) | 0,64 | 0,80 | 0,40 | 0,49 | 0,900 |

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# The Sound of Joy, the Sound of Hardness

## 3.1 The Sound of Hardness – Take Home Message

The timbre features, which are associated with the impression of **musical hardness**, have been identified as: **high tempo**, **low dynamic distribution**, **noisyness** (lack of clear melodic lines), **percussive energy**, **rhythmic density.**

With the help of these sound properties, a more or less genre-independent **hardness model** has been developed = "**Musical Hardness**".

The hardness model can be easily integrated into a **software application** that allows e.g. interactive sound/music searches.

**Long-term goal** is – among other things – the development of a **mobile application** for the detection of musical hardness.

# The Sound of Joy, the Sound of Hardness

## 3.1 The Sound of Joy 乐

The use of the same Chinese character for **music** (音乐 yīnyuè) and **joy** (乐 yuè) implies, that both concepts could have a certain connection.

Developement of the character 乐, Chinese characters for joy (yuè) and music (yīnyuè) in different styles (bottom right: original character)

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**Which timbre features can be found in Chinese music for the expression of joy, and which ones can be found in European music?**

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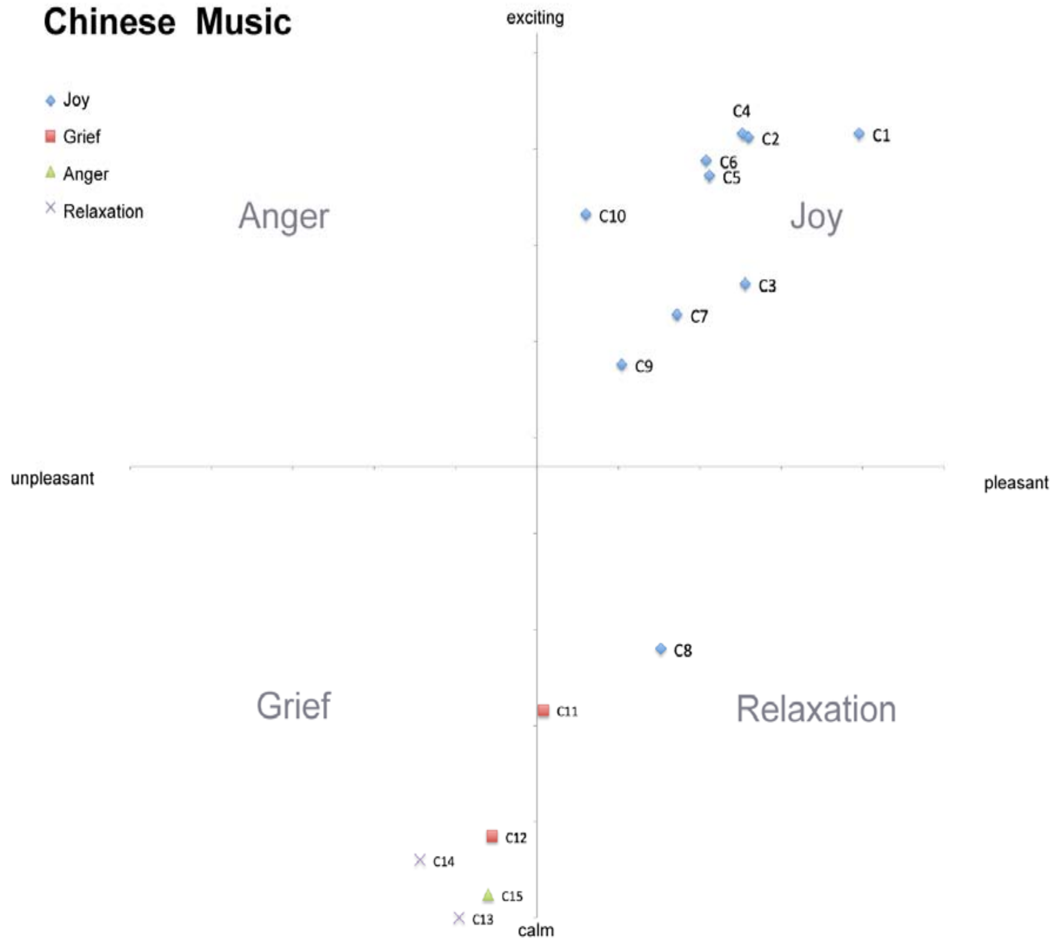
**Are there culture-specific differences or similarities in the typical timbre features for the expression of joy?**

Developement of the character 乐, Chinese characters for joy (yuè) and music (yīnyuè) in different styles (bottom right: original character)

# The Sound of Joy, the Sound of Hardness

## 3.1 The Sound of Joy

45 Europeans listened to excerpts of **15 Chinese** and **15 European** music pieces with the task to rate the **expressed valence** (pleasant vs. unpleasant) and **arousal** (calm vs. exciting).




Ratings of the Chinese music pieces by European listeners (Yang 2019, p. 46)

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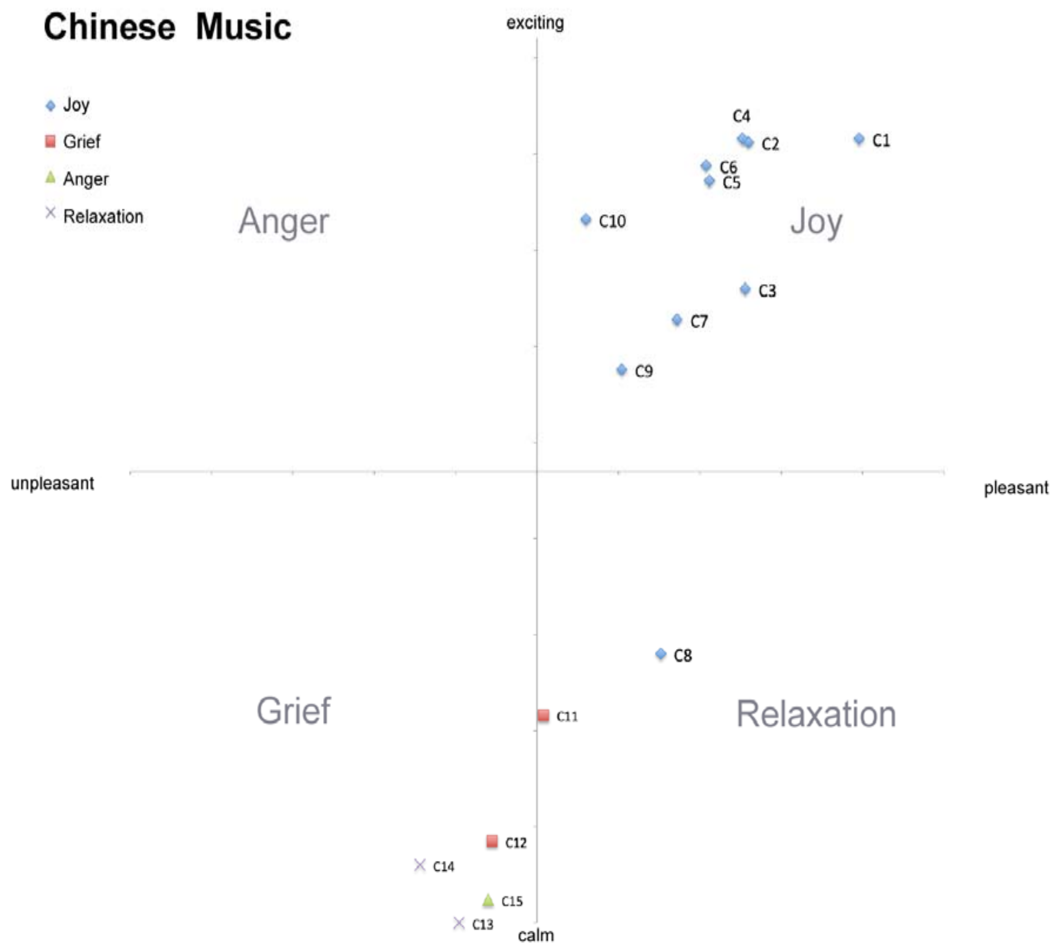
10 of the Chinese and 10 of the European pieces are **considered in the literature** to be **particularly joyful** within the respective culture, while the remaining 5 corresponded to other emotions.

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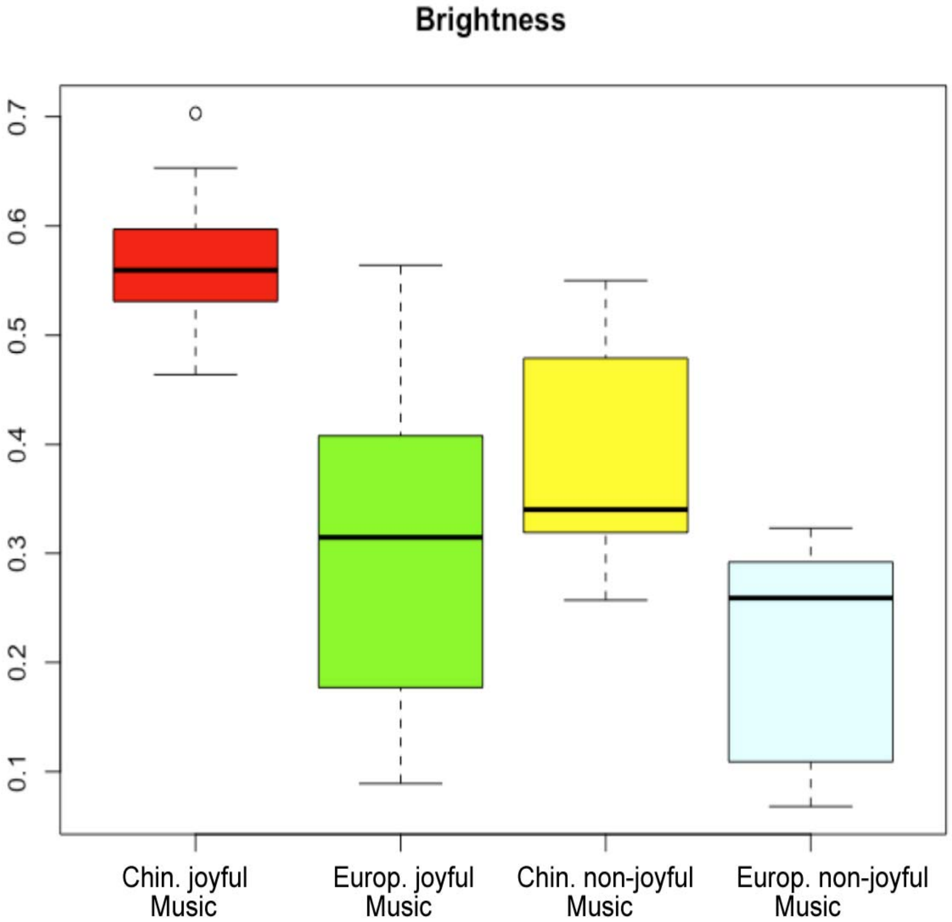
# The Sound of Joy, the Sound of Hardness

## 3.1 The Sound of Joy

In a next step the values of **valence** and **arousal** have been tested for **correlation** with 41 timbre features.



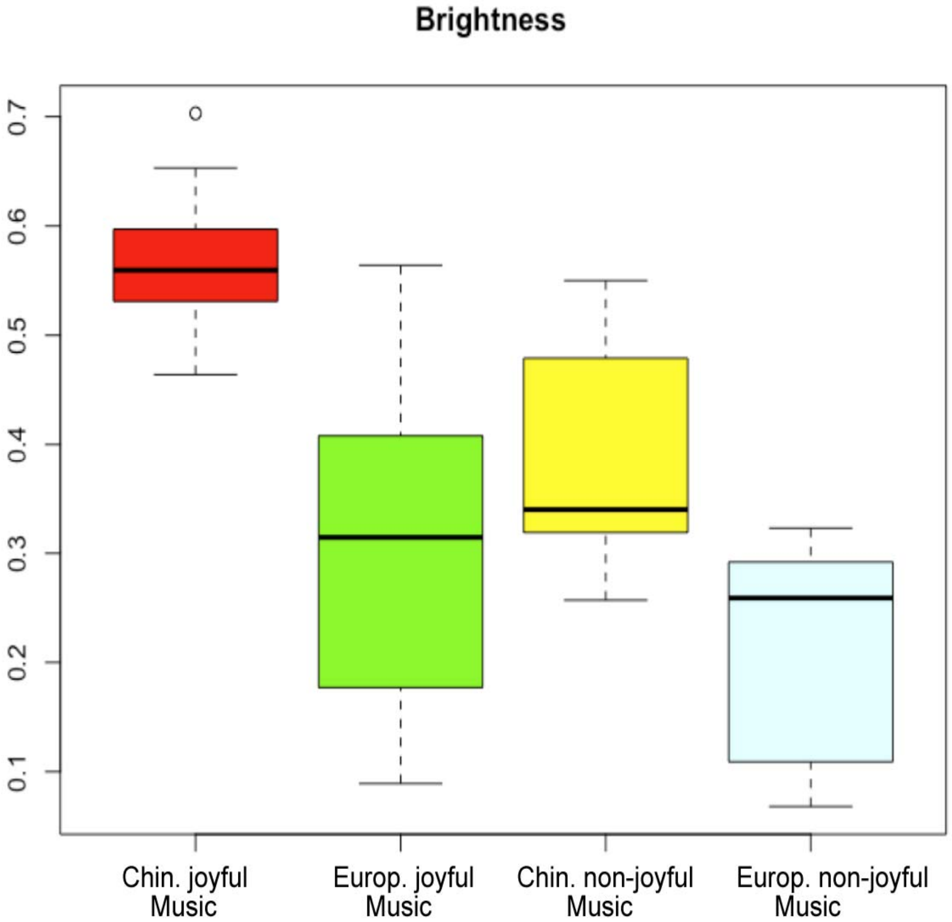

Brightness in Chinese vs. European joyful and non-joyful music (Yang 2019, p. 52)

# The Sound of Joy, the Sound of Hardness

## 3.1 The Sound of Joy

In a next step the values of **valence** and **arousal** have been tested for **correlation** with 41 timbre features.

While both European and Chinese **joyful music** pieces correlate strongly with a **high** value for **tempo** (event density), the timbre features related to **brightness** (like spectral centroid, spectral rolloff, spectral flatness and zero crossing rate) had significantly **higher** values for **Chinese joyful music** than for European joyful music.

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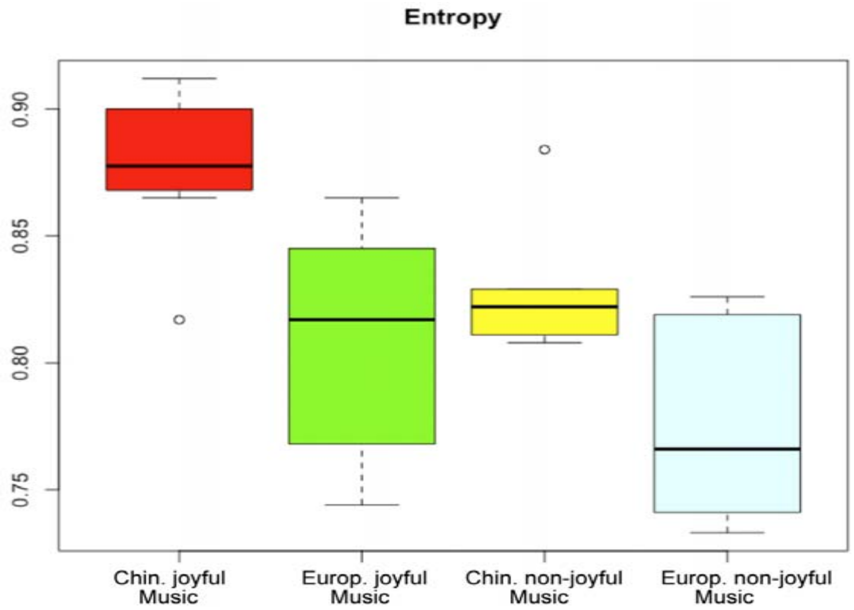
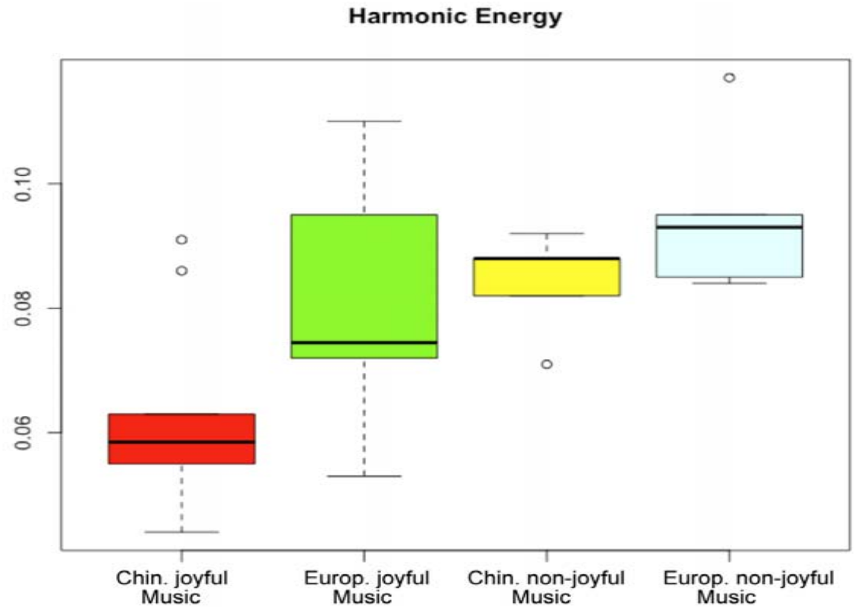
# The Sound of Joy, the Sound of Hardness

## 3.1 The Sound of Joy

Furthermore, typical for **Chinese joyful music** seem to be a greater amount of **(percussive) noise**, appearing in the comparatively **high** value in **spectral entropy** as well as in the **low** value in **harmonic energy** (less harmonic partials).




Spectral Entropy in Chinese vs. European joyful and non-joyful music (Yang 2019, p. 53)




Harmonic Energy in Chinese vs. European joyful and non-joyful music (Yang 2019, p. 67)

# The Sound of Joy, the Sound of Hardness

## 3.1 The Sound of Joy – Take Home Message

The **expression of joy** in Chinese music is **clear enough** that also European listeners perceive it as joyful.

Chinese and European **joyful music** is characterized by a **fast tempo** (high value for event density).

Joyful Chinese music is **brighter** (higher values for spectral centroid, spectral rolloff, spectral flatness and zero crossing rate) and **more noisy/percussive** (higher value for spectral entropy, less harmonic partials) than European joyful music.

# The Sound of Joy, the Sound of Hardness

## 4 Chills – Bigger than Joy

Chills are short-term **emotional** and **physical arousals** that occur while listening to **particular emotional moving** parts of music.

With emotionally engaging music,
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Chills are **independent** of age, gender and musical education.
(Blood & Zatorre 2001; Schönberger 2006, p. 28; Altenmüller et. al. 2007, p. 63)

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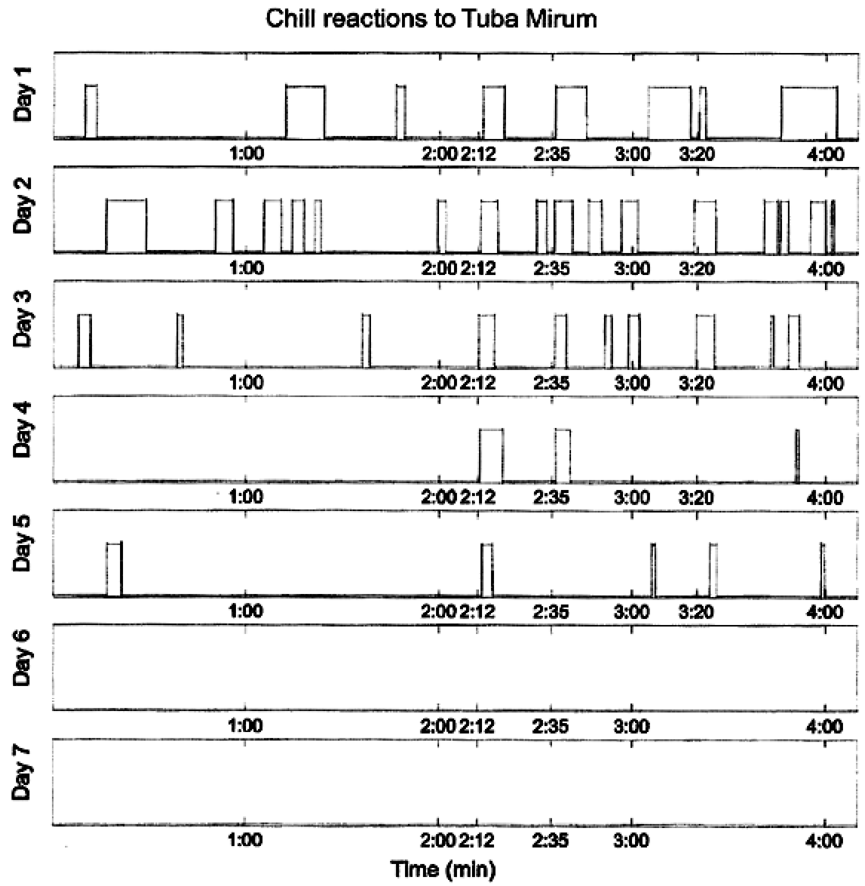
# The Sound of Joy, the Sound of Hardness

## 4 Chills – Bigger than Joy

### Contrastive valence theory

(David Huron, since 2005)

An **unpleasant** feeling directly followed by a **pleasant** one makes the pleasant feeling **even more pleasant** than normal.




Chill experiences of a test person listening to Mozarts "Tuba Mirum" for several times (Grewe, Nagel, Kopiez, Altenmüller 2007, p. 305)

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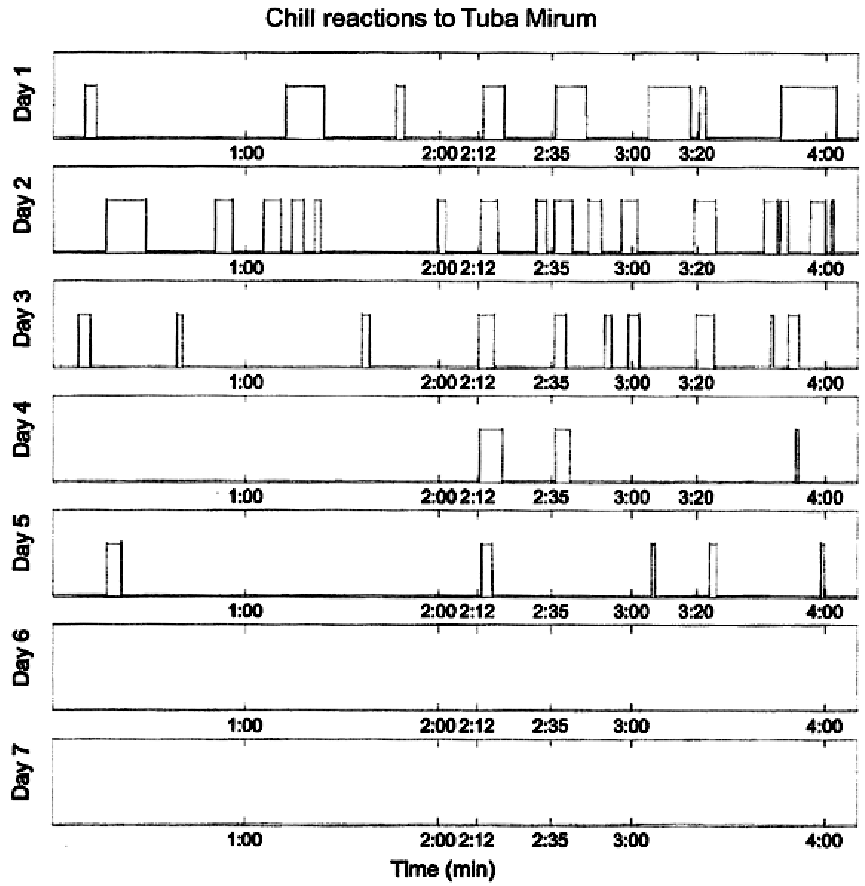


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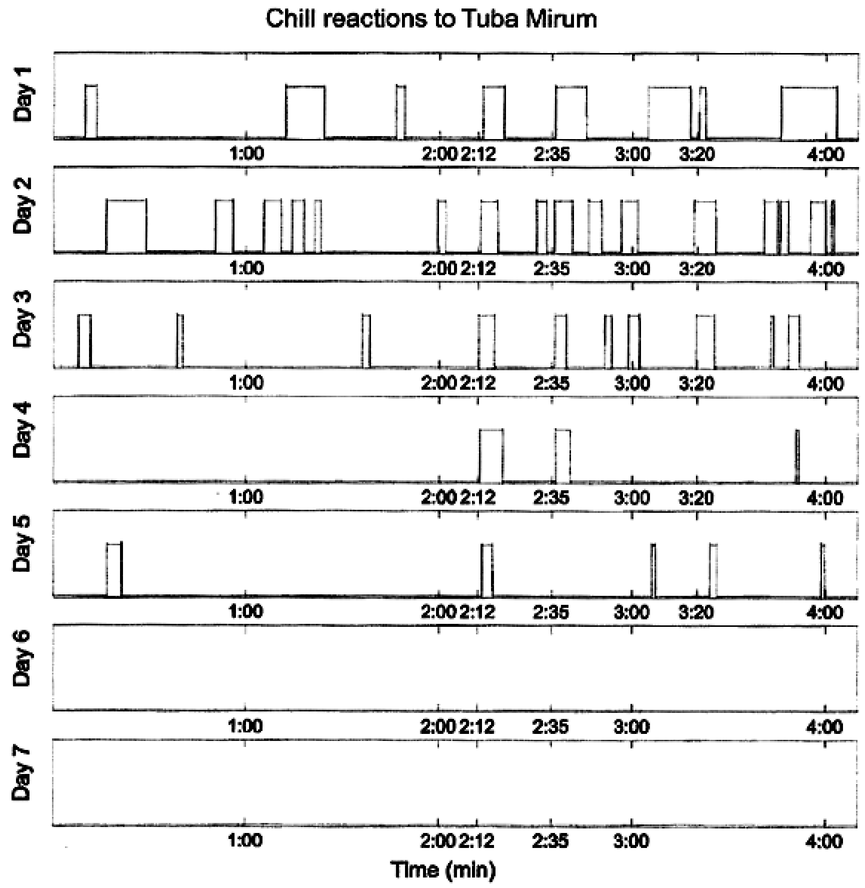
This reaction to and **coping with** a sudden and **unexpected stimulus** manifests itself in a **chill**, which is usually perceived as **pleasure**, as music means no danger.

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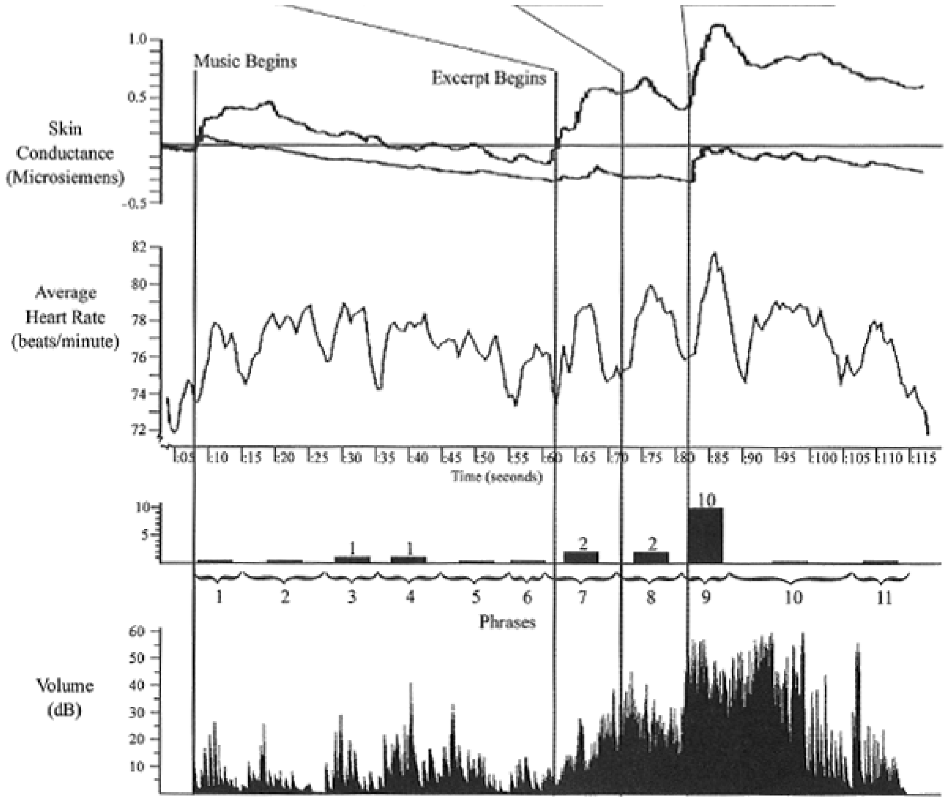


Chill experiences of 10 test person listening to Mozarts Piano Concerto K. 488, 2nd movement (Guhn, Hamm, Zentner 2007, p. 477)

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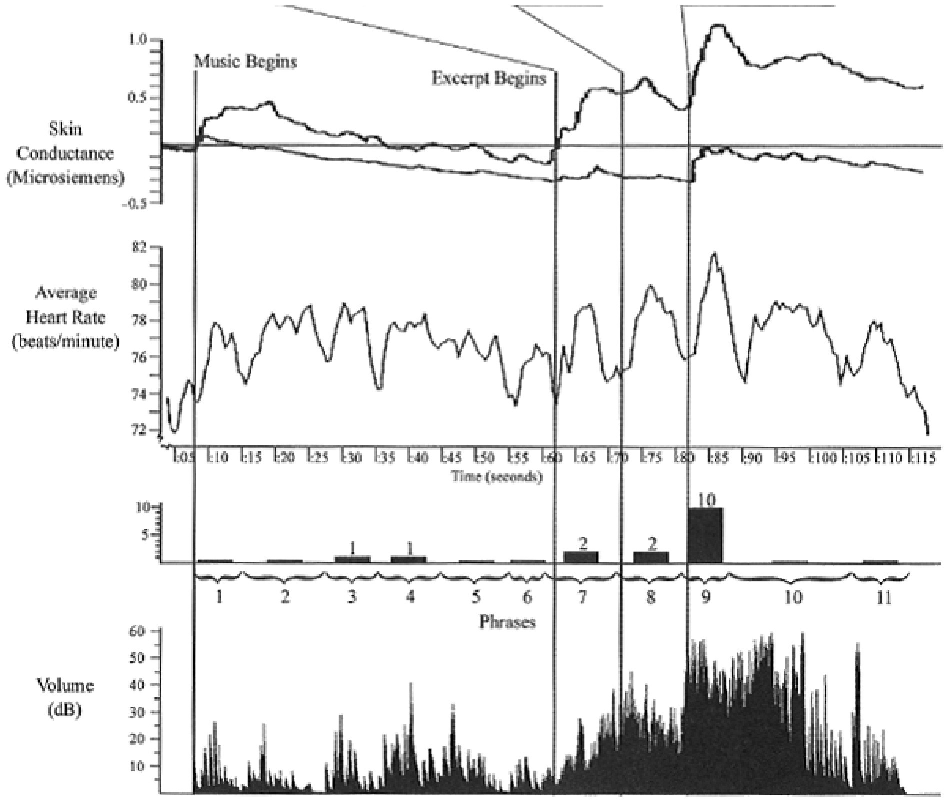


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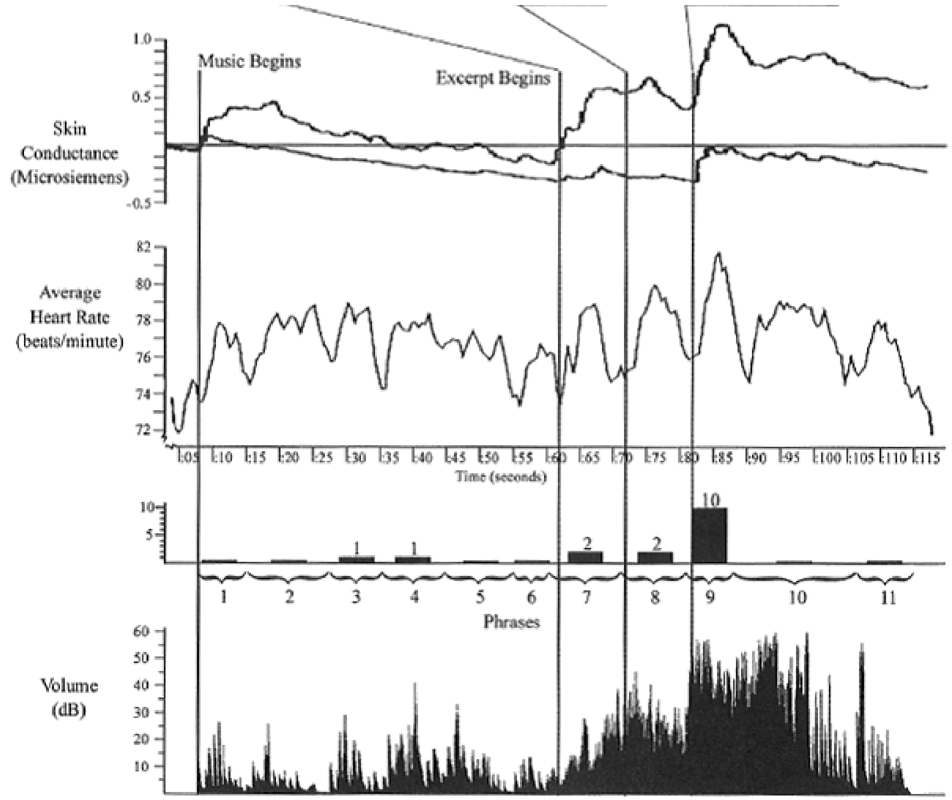


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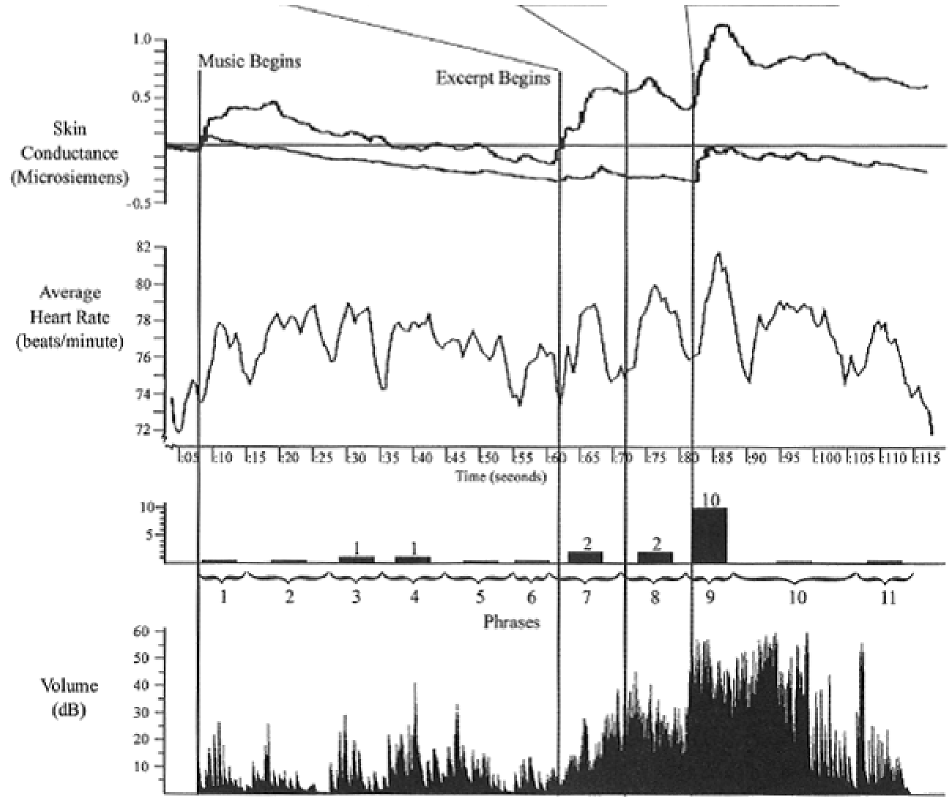


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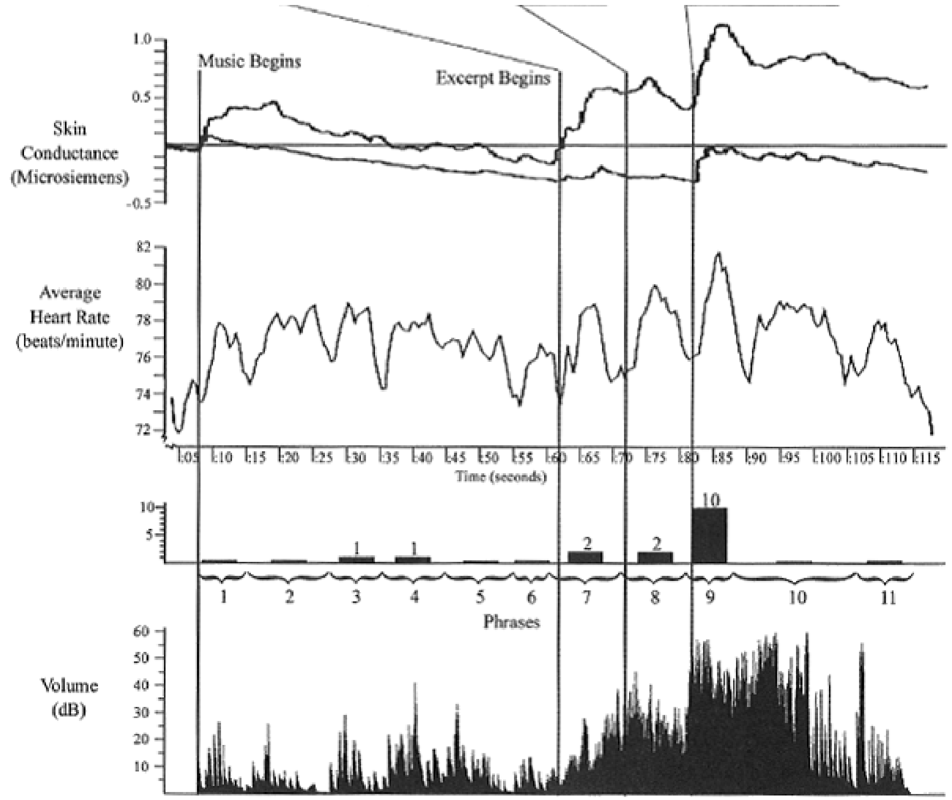


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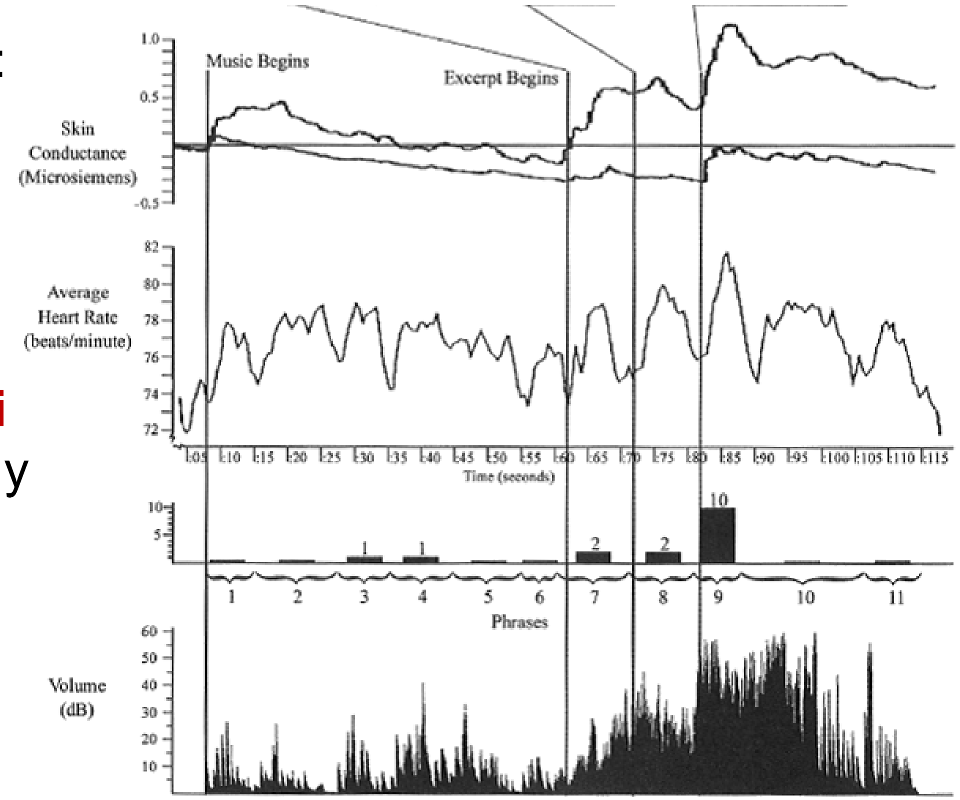


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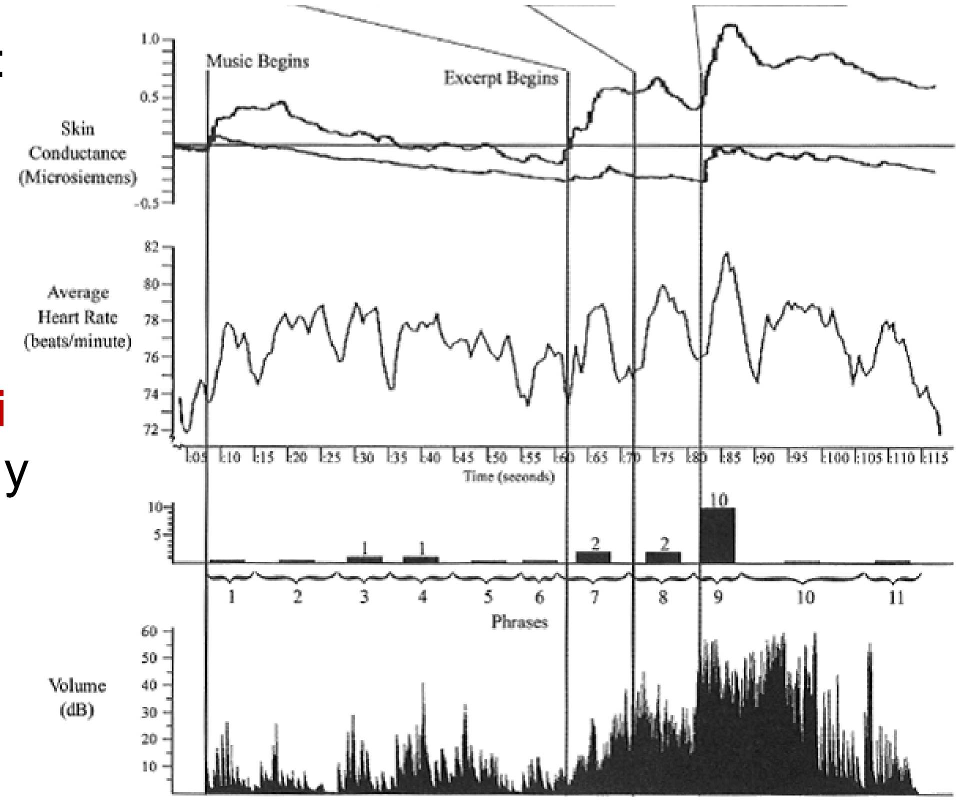


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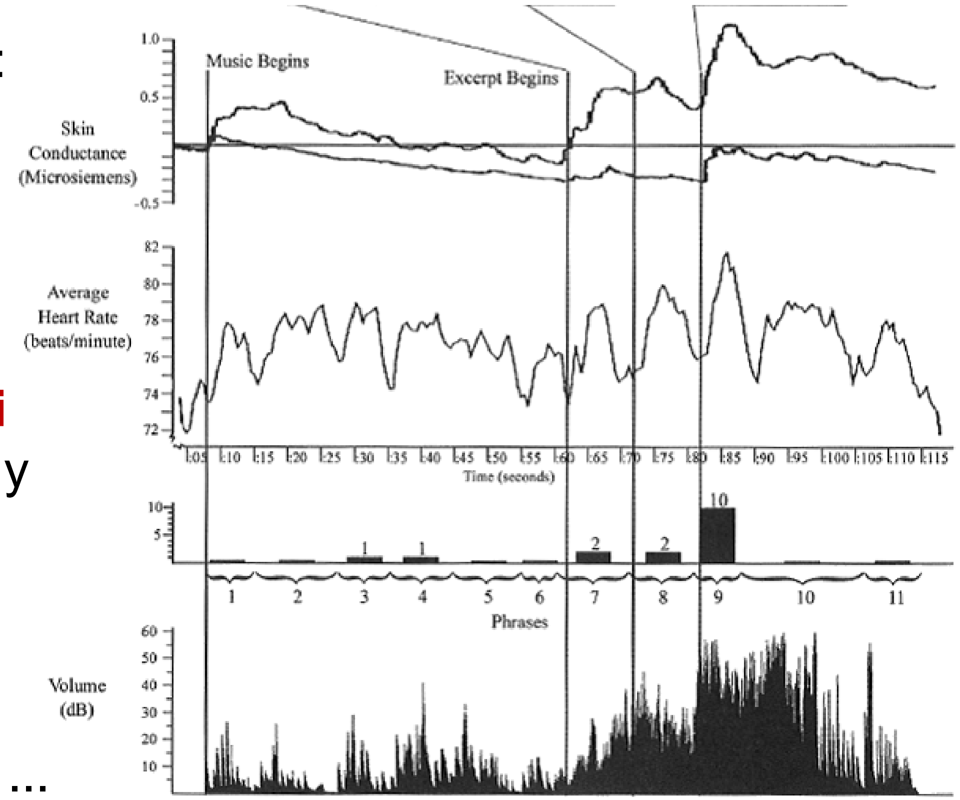


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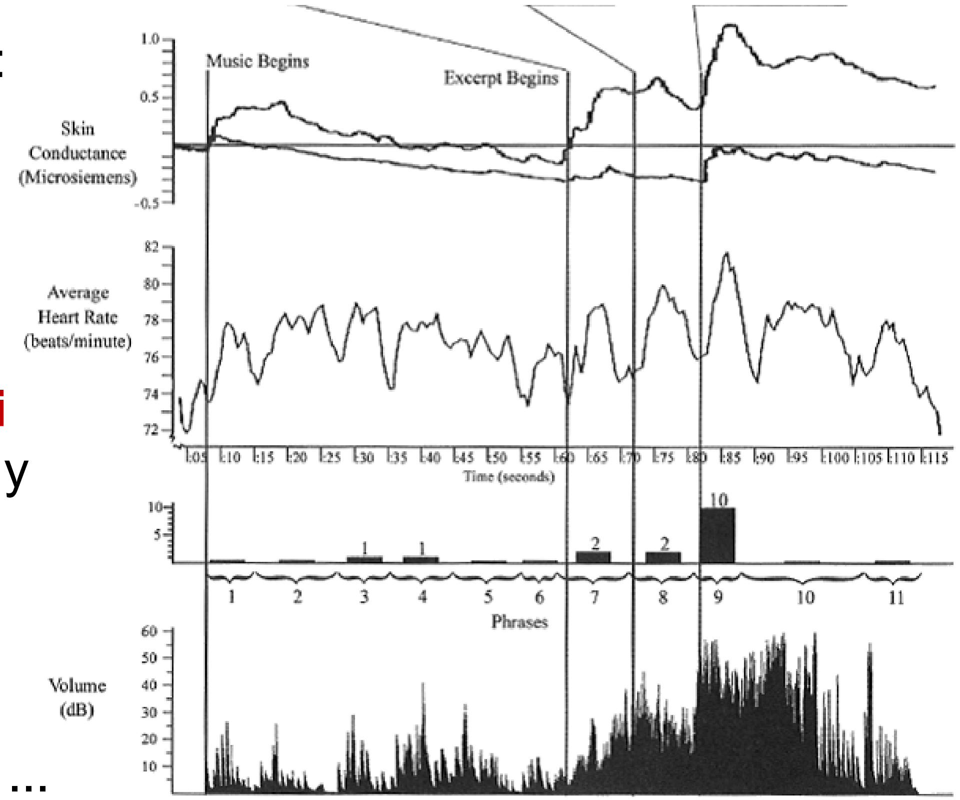
- **broadly speaking: violations of musical expectations**

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### Influence of Alcohol on music-induced Chills:

39 subjects listened in an interval of two weeks to a musical piece ("What a wonderful world", interpreted by Eva Cassidy) in **two conditions**: one group started **sober**, the other started slightly **alcoholized** (0.5-0.8 alcohol level).


MindMedia Nexus10II Biodata-Logger for EEG, EMG, skind conductance, temperature, muscle tone, heart rate, oximetry etc.

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Listeners had to **press a button** on each **chill** experience while their skin conductance, blood pressure, heart rate, and muscle tone have been measured **music-synchronous** by a biodata-logger (MindMedia Nexus10II)


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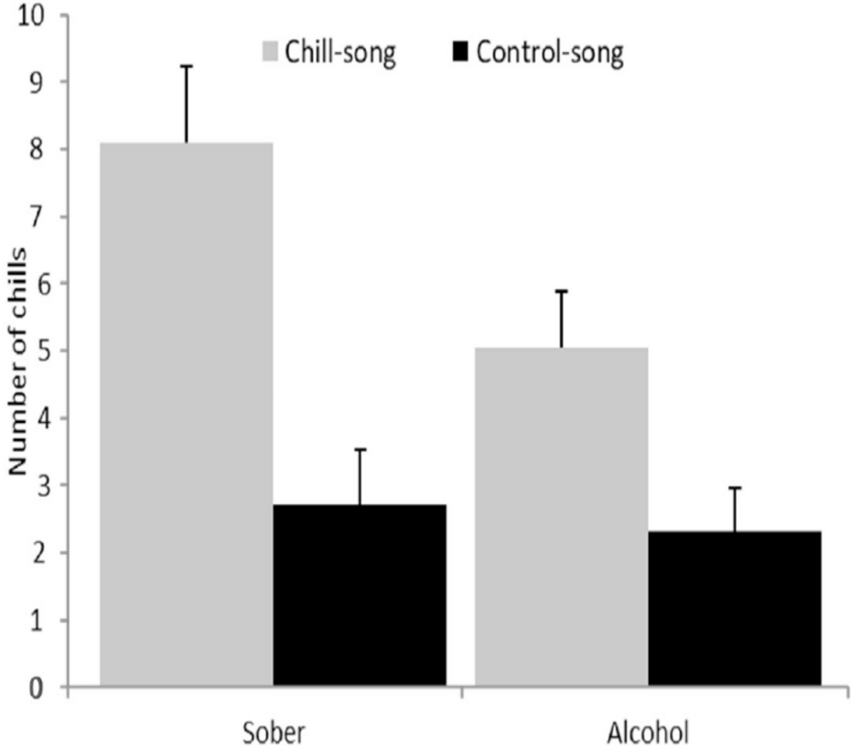


Chill experiences with and without alcohol (Starcke, von Georgi, Tiihonen, Laczika, Reuter 2019, p. 29)

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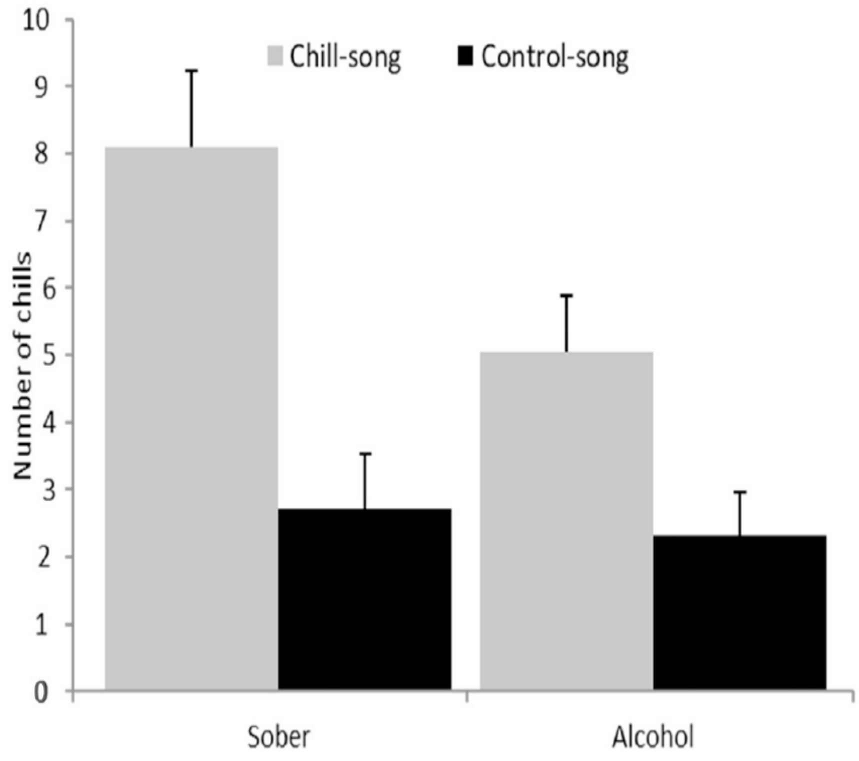


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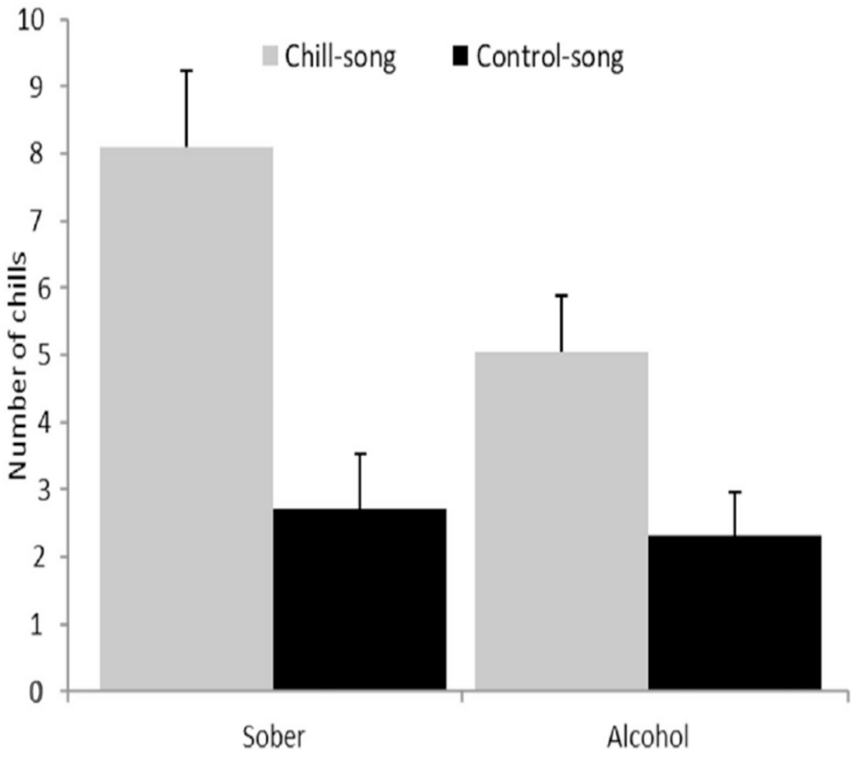


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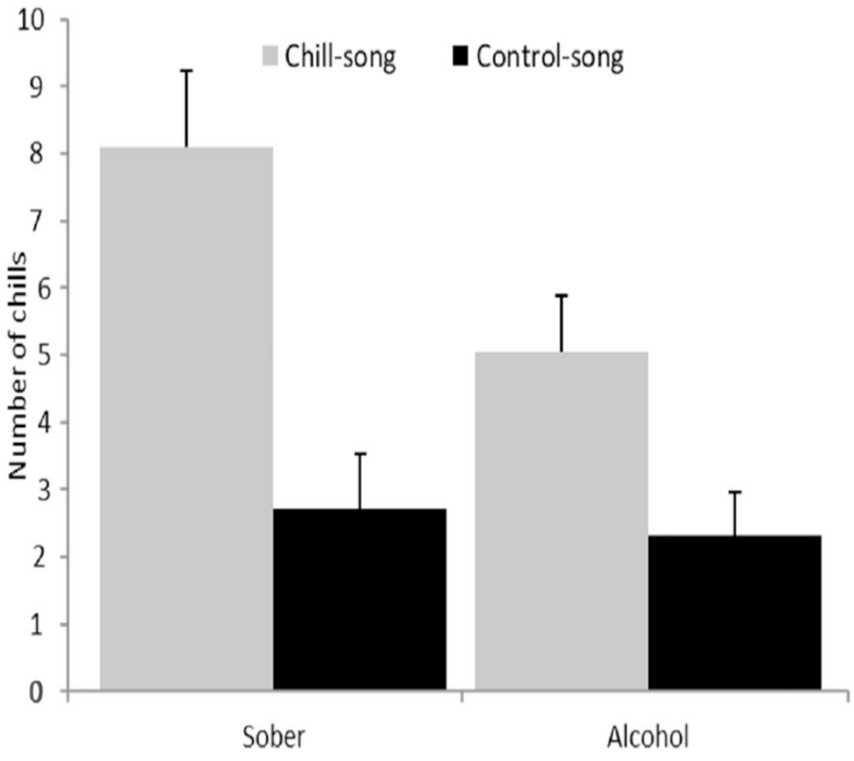
- Listeners experience significantly **more** chills **sober** than in the alcoholized state.
- Chills under the influence of **alcohol** are experienced **elsewhere** than in sober state.

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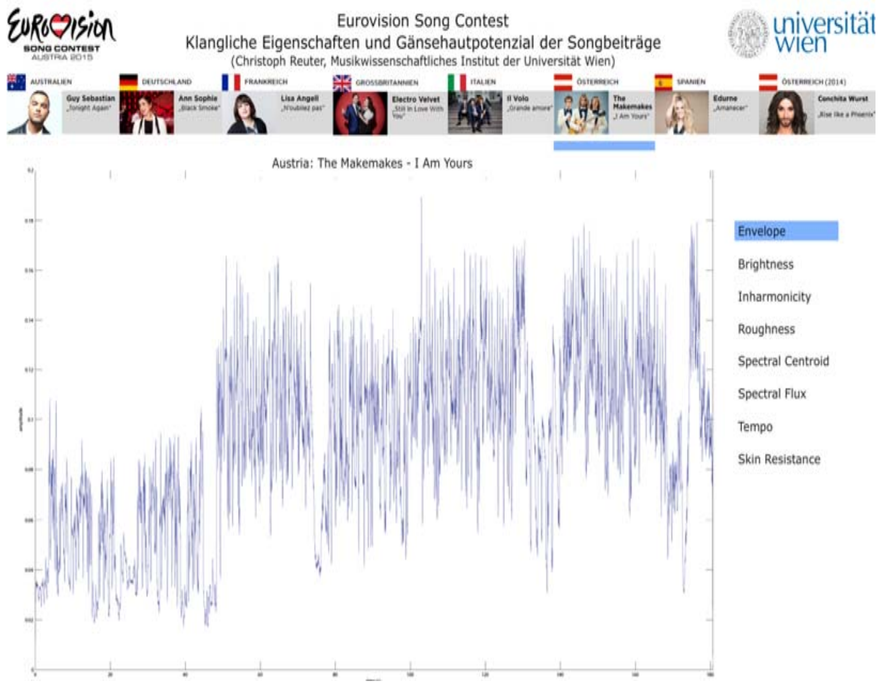
# The Sound of Joy, the Sound of Hardness

Fun Fact ☺

## 4 Chills – Bigger than Joy

### Chills at the Eurovision Song Contest:

In order to measure the **emotional involvement** of the listeners, on behalf of the Austrian Broadcast (ORF) some of the songs of the Eurovision Song Contest 2015 were examined for their **chill- or goose-bump-factor** for the scientific TV-program "Newton".




[Measurement of chill experiences and skin conductance for selected songs of the Eurovision Song Contest 2015 (Reuter 2015)]

# The Sound of Joy, the Sound of Hardness

Fun Fact ☺

## 4 Chills – Bigger than Joy

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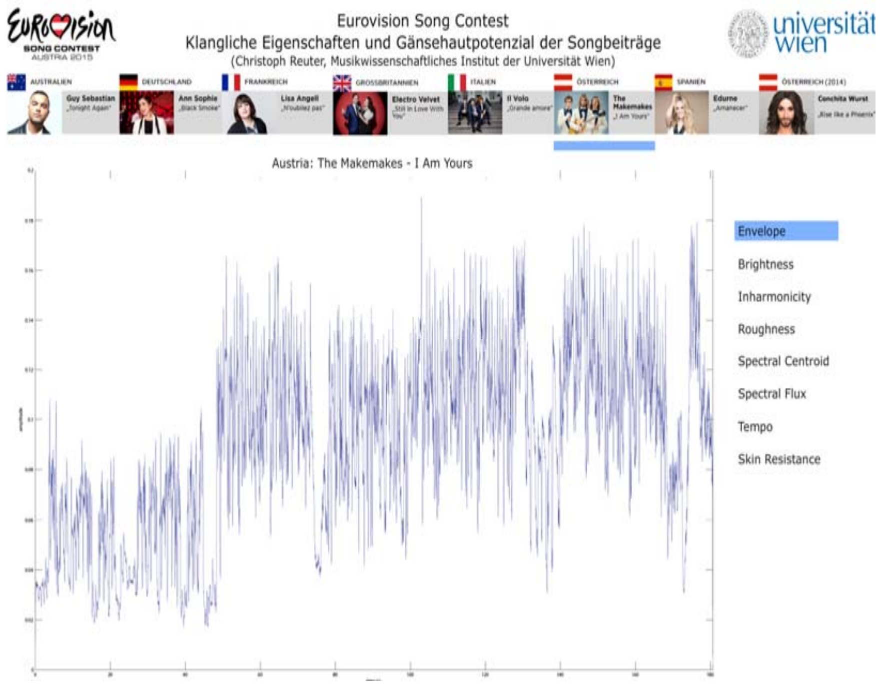
**Result:** The Italian contribution "Grande Amore" (by Il Volo) scored the **most chills**, and in fact, in pure televoting Italy was **366 points ahead** of Sweden (279) and Russia (286) on the decisive evening.

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## The Sound of Joy, the Sound of Hardness

谢谢

## 4 Chills – Bigger than Joy – Take Home Message

Chills are short-term **emotional** and **physical arousals** that occur while listening to **particular emotional moving** parts of music.

Chills can be **measured** by an increase of the **skin conductance**.

Chill-triggering moments in music are: **sudden changes** in timbre, dynamics, harmony, **abrupt switches** between solo and tutti or loud and soft, **emotional buzzwords** and system-compliant violations of **musical expectations**.

Listening to music under the **influence of alcohol** leads to **less** chills at **altered** positions in the musical piece.

**Chills** combined with the measurement of **skin conductance** could be a good **predictor** for a listener's **emotional involvement** into a certain song (**musical hit prediction**).