Exploring the reward prediction error (RPE) and its relevance to music

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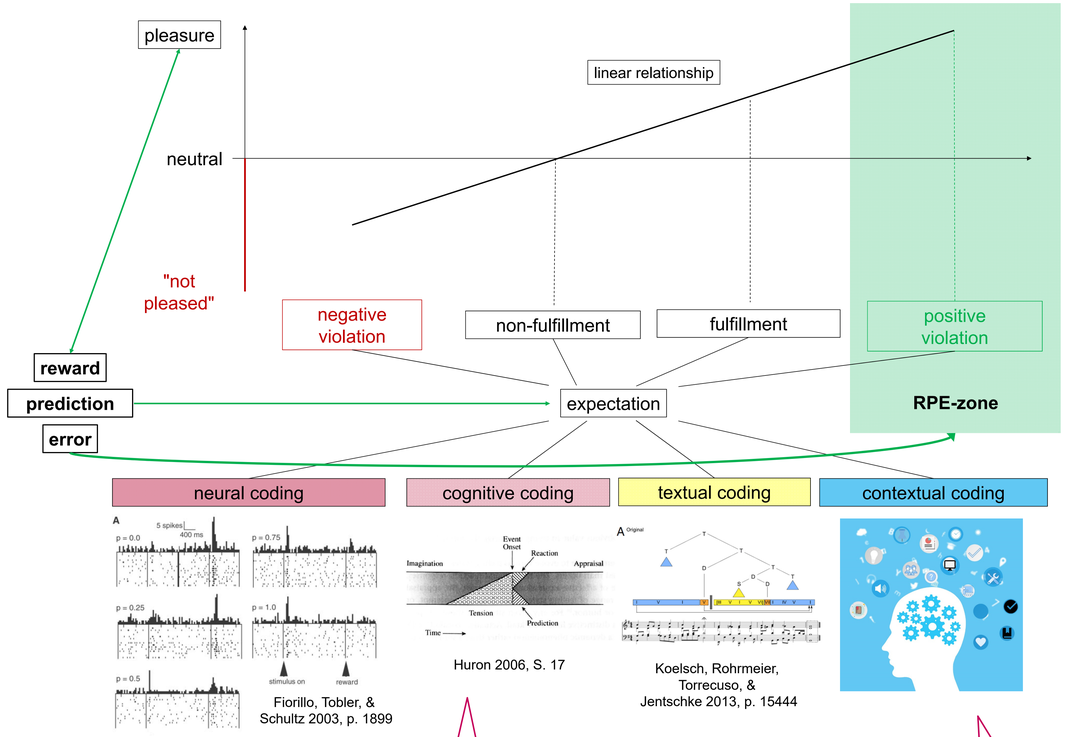
Introduction

- The **reward prediction error (RPE)** is a relatively young psychological concept discovered in 1993 by a group of neuroscientists (Schultz, Apicella, & Ljungberg 1993). Surprising only at first glimpse, **pleasure is maximized when a presented reward was least expected**. This is compatible with everyday notions and happens with unexpected gifts for Christmas, unexpected lottery-wins, or those of (inferior) sports teams etc.
- I am suggesting here to transfer and extend the concept of the **reward prediction error (RPE)** to music and its **aesthetic appreciation** (green box in diagram below).
- Until recently, Neuroscience often treated **expectations in music** in a binary fashion, **allowing only fulfilment or violation**.
- **Aesthetic issues**, however, are **more complex** and meeting the most straightforward expectation (such as the tonic after the dominant an a cadence) might only result in **average aesthetic appreciation**.
- **Skilfully expanding or even breaking the rules** might instead lead to **higher aesthetic appreciation** and (if accepted) open the door to artistic and cultural development.
- These kinds of violations may thus extend from the micro-level of milliseconds to the meso-level of formal processes up the macro-level of historical stylistic change in music.



Fiorillo, Tobler, & Schultz 2003, p. 1899

Huron 2006, S. 17

Koelsch, Rohrmeier, Torrecuso, & Jentschke 2013, p. 15444

shorter ← addressed musical duration → longer

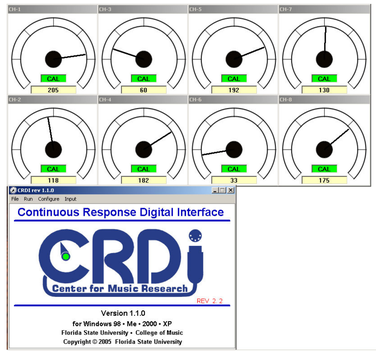
higher ← degree of empirical verification → lower

- In a groundbreaking experiment, Fiorillo, Tobler, & Schultz (2003) refined the **neural coding** of reward and the effect of **positively violated expectations**. It was shown that the response of dopaminergic neurons is maximized when a presented reward was least expected (p indicating probability values). I am assuming here that similar effects are at stake in music, when expectations, their fulfillment, negative or **positive** violations occur as music unfolds in time.

- Huron (2006) developed the **ITPRA Theory of expectation in music with** the five stages (I) imagination response,
- (T) tension response,
- (P) prediction response,
- (R) reaction response and
- (A) appraisal response. This is indicated in the schematic diagram. It may serve as an example for **cognitive coding** of expectation.

- Music theory from Schenker (1906) to Margulis (2007) and beyond addresses **textual coding** of expectations in the musical structure. Koelsch et al. (2013) add the important distinction of **hierarchical layers** and provide empirical evidence based on Event-related potentials. Also, a musical style (Rosen 1971) creates a textual framework of expectations. "Hit prediction science" (Pachet & Roy 2008) is based on textual analysis of non-vectorised audio material.

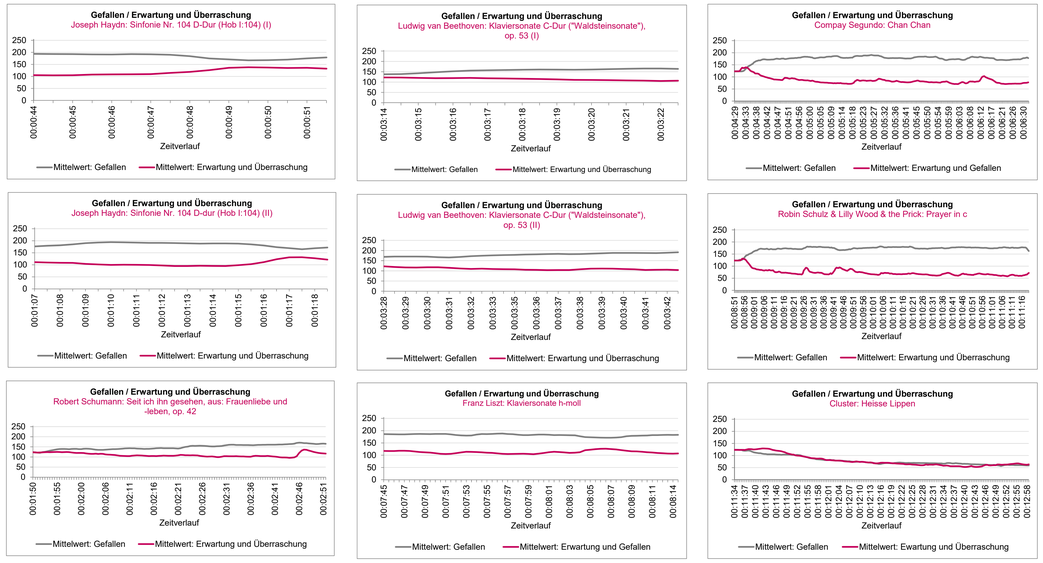
- In his chapter "Expectation and learning" Meyer (1956) addresses **contextual codings** of expectations in music. Meyer mentions a **cyclic alternation of change and stability** in art music and jazz. Peterson & Berger (1975) identify **similar cyclic processes** in cultural production based on music industry data. A follow up is provided by Christianen (1995).



Example	Mentioned by:	Textual peculiarity	Correlation (Pearson) expectation / liking
Haydn Symphony No. 104 D major (I)	Margulis (2007)	Upbeat followed by silence	-0.97
Haydn Symphony No. 104 D major (II)	Margulis (2007)	Repetition	-0.94
Schumann – Seit ich ihn gesehen op. 42	Margulis (2007)	Deceptive cadence	-0.31
Beethoven Waldstein-sonata op. 53 (I)	Margulis (2007)	Modulation from C major to Bb major, then to d minor	-0.85
Beethoven Waldstein-sonata op. 53 (II)	Margulis (2007)	Modulation from C major to d minor	-0.67
Liszt piano sonata b minor	Rohrmeier & Koelsch (2012)	Interchange of expectation and surprise	-0.72
Compay Segundo – Chan Chan	Own example	Various accents of voice and timbre	-0.72
Robin Schultz – Prayer in C	Own example	Breaks with hissing noise	-0.87
Cluster – Heisse Lippen	Own example	Hardly any musical development	-0.96

Method

- To provide for additional empirical verification, **Continuous response measurement** of **surprise** (purple curve) and **appreciation** (grey curve) was applied to a number of music examples (see table above) using the interface introduced by Geringer, Madsen, & Gregory (2004).
- As previously shown by Egermann, Pearce, Wiggins, & McAdams (2013), **it is possible to empirically capture expectation in music.** We then correlated these findings with ratings of aesthetic appreciation in an own study (Thesis, Römer 2016).
- The **curves are negatively correlated throughout** → if one goes up, the other one (mostly) goes down.



Conclusions

- Increasing surprise predominantly leads to negative aesthetic appreciation which means **an effect of the reward prediction error could not be observed.**
- Instead, the degree of surprise seems to turn into an **additional criterion for empirical aesthetics**, where average complexity, average length, average loudness, average tempo etc. is rated best. This **complies with findings** from a recent study by Gold, Pearce, Mas-Herrero, Dagher, & Zatorre (2019).
- However, **various textual layers in music overlap** (melody, harmony, rhythm and many more), partly in hierarchical fashion (Koelsch, Rohrmeier, Torrecuso, & Jentschke 2013), **and so do layers of expectation**. They can empirically only be grasped if they are clearly foregrounded / predominant, so the above **findings might be limited.**
- While processes of expecation and their fulfillment or negative / positive violation have only been studied on a **micro-level** time-scale, they may just as well be at stake at the **meso-level of formal processes** and the **macro-level of historical stylistic change** in music.
- For now, from a **musicological perspective**, the **reward prediction error** might serve as a **metaphor** explaining cultural developments in larger time scales.
- Additional empirical verifications from various disciplines are needed.

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