Rhythm and other stories: naturalistic and neurobiologically-relevant approaches in language comprehension

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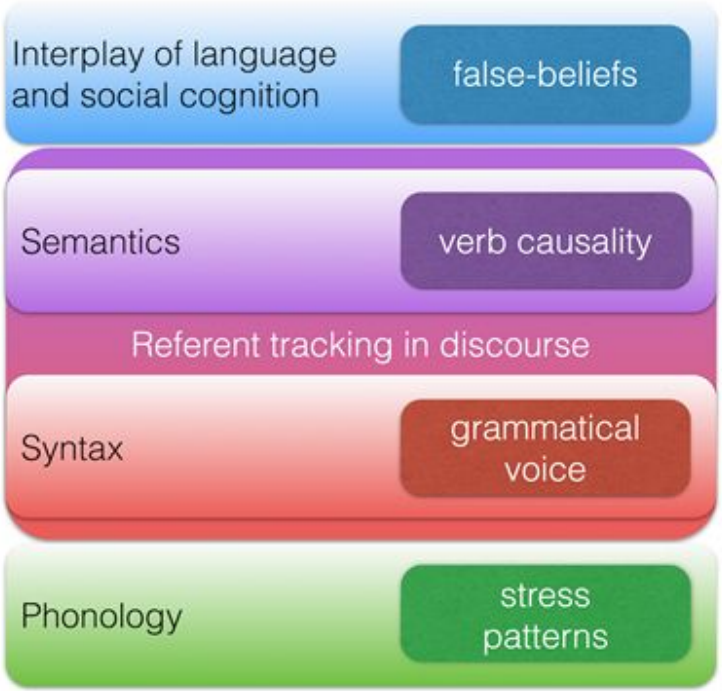
Previous fMRI results
New experiment - EEG & behavioral
Behavioral results
EEG experiment (work in progress)
Maastricht University

A little bit of background

- I am a linguist
- I fell in love with Syntax at Year 2
- Syntax 1 - awesome, Syntax 2 - suspicious
- Wondering whether these rules are true
- Master in Language Science and Technology
- Fell in love with experimental work
- Causality and animacy
- Still wondering whether the brain cares about the categorisations made by linguists
- PhD naturalistic experiment - to find out what the brain is sensitive to and how

My PhD



- **auditory** stimuli: spoken language comprehension

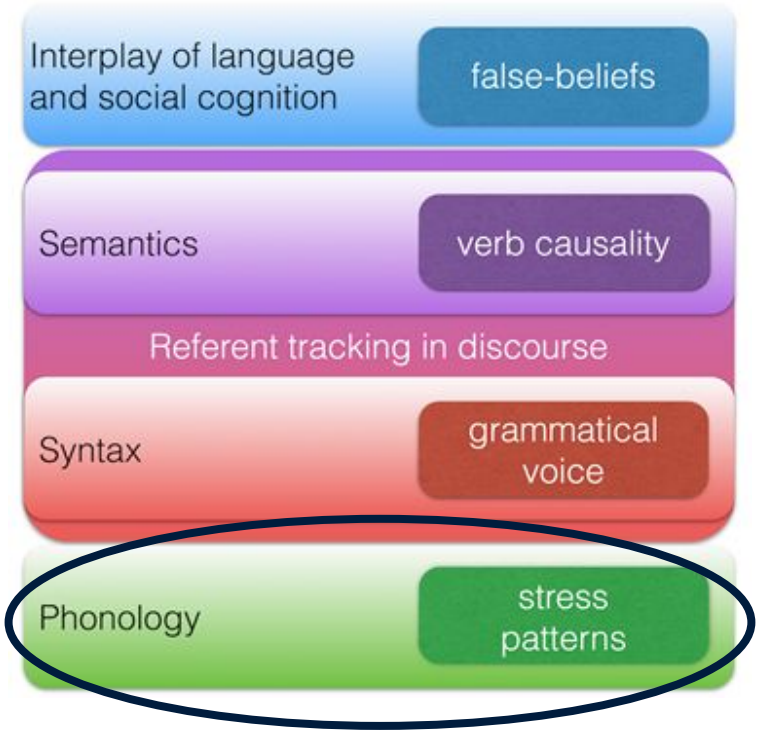
- naturalistic **stories**: extended context, room for manipulations at many linguistic levels within the same context

- critical events (compound words, noun phrases, sentences) **embedded** in their natural context

- naturalness: rich **context** and **auditory** modality

Kandylaki et al. 2015, *HBM*; 2016, *JNeurosci*; 2017, *JoCN*

My PhD



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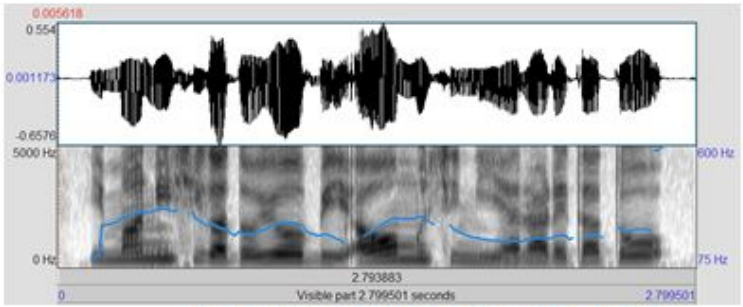
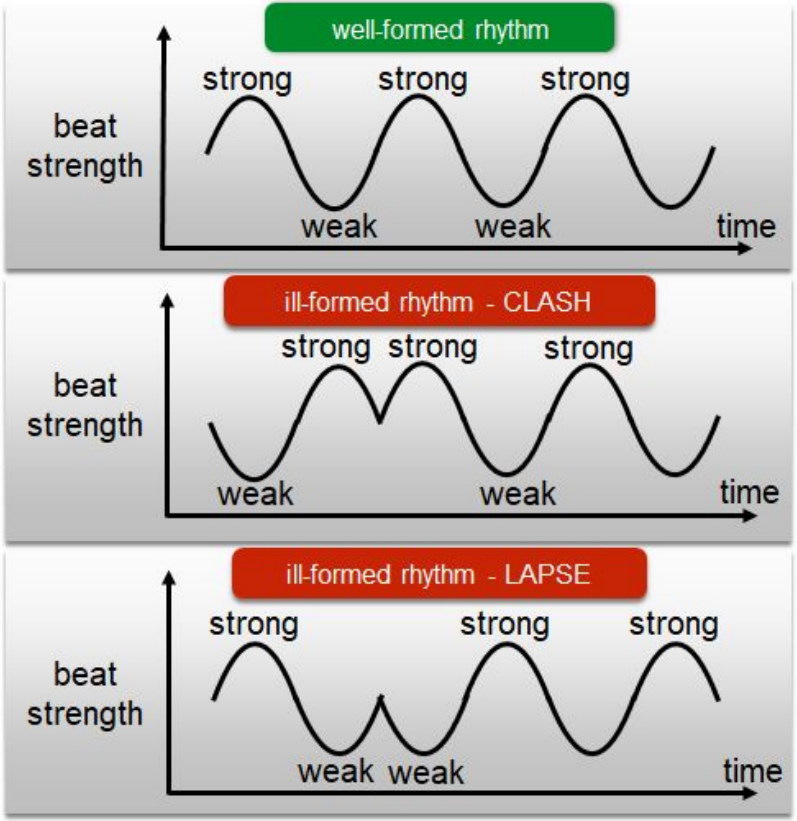
Kandylaki et al. 2015, *HBM*; 2016, *JNeurosci*; 2017, *JoCN*

Rhythm in language and the Rhythm Rule (RR)

limericks





Kandylaki & Henrich, 2014, *CogSci*; Kandylaki et al. 2017, *JoCN*

Rhythm regularity in compounds

Linguistic rhythm: lexical stress interacting with rhythmical stress

Rhythmically ill-formed
CLASH

Holz Spielzeug

wood toy

Rhythmically well-formed
SHIFT

Holzspielzeug

wooden toy

Kandylaki et al. 2017, *JoCN*

Rhythm regularity in compounds

Linguistic rhythm: lexical stress interacting with rhythmical stress

Rhythmically well-formed
NO-SHIFT

Plastik Spielzeug

plastic toy

Rhythmically ill-formed
LAPSE

Plastik Spielzeug

plastic toy

Kandylaki et al. 2017, *JoCN*

2x2 design of lexical stress and rhythmical well-formedness

	Well-formed rhythm	Ill-formed rhythm
Correct lexical stress	***NOSHIFT*** 'PLAStik – spielzeug (plastic toy) 	***CLASH*** 'HOLZ – spielzeug (wooden toy) 
Incorrect lexical stress	***SHIFT*** 'HOLZ – spielzeug (wooden toy) 	***LAPSE*** 'PLAStik – spielzeug (plastic toy) 

Kandylaki et al. 2017, *JoCN*

Compound words

Story 105 – Zirkus

Der Clown Valentino genießt das Leben im Zirkus 'Fiorello', da sie viel herumreisen. Jedoch will der Zirkus bald auch ein festes Zirkuszelt für die Winterzeit bauen. Jetzt benötigen sie nur noch ein passendes Baugrundstück$_{CLASH}$ und schon kann der Bau beginnen. Neulich trug$_{ACT-HIGH}$ der Clown bei einem Auftritt die Prinzessin auf Stelzen durch die Manege, was die Zuschauer sehr amüsiert hat. Der Clown machte dabei lustige Fratzen, griff in sein rotes Stoffsäckchen und warf der Dame in der ersten Reihe ein kleines Holzspielzeug$_{SHIFT}$ zu. Im improvisierten Sketch nahm der Clown einen Kuschelbär, eine Zahnbürste und ein Kissen aus seinem Säckchen. Als er an den Rand der Manege kam und vorgab, sich die Zähne zu putzen, stand er mit dem Rücken zur Prinzessin. In dem Moment klaute die Prinzessin den Kuschelbär und versteckte ihn unter ihrem Kleid. Als der Clown sich ins Bett legen wollte, konnte er sein Kuscheltier nicht finden. Und weil er so verwirrt aussah,$_{TOM}$ mussten alle Zuschauer herzlich lachen. Dann wurde der Clown von der Prinzessin gestoßen$_{PASS-HIGH}$ und unter dem Kleid kam der Kuschelbär wieder hervor. Der Clown freute sich, sein Kuscheltier wiedergefunden zu haben! Dann nahm er einen Kohlemalstift,$_{LAPSE}$ aus seiner Tasche und fing an, etwas zu zeichnen. Als er seine Zeichnung dem Publikum zeigte, schien ein Zuschauer sehr fasziniert davon. Der Clown ging näher zu ihm und unterhielt sich mit ihm über das Kunstwerk.$_{NONTOM}$ Der Zuschauer mochte$_{ACT-LOW}$ den Clown, und weil die Zeichnung ein ganz skurriles Porträt der Prinzessin war, wurde die Diskussion sehr lustig. Schließlich stand der Zuschauer auf und brachte das ganze Publikum zum Klatschen. Zum Dank schenkte der Clown dem Zuschauer die Zeichnung.Der Zuschauer wurde von dem Clown für seine freundliche, mitreißende Art geschätzt$_{PASS-LOW}$. Das Publikum klatschte und johlte begeistert. Der Zuschauer war nämlich vielen aus den Medien als der Landesvolkswirt$_{NOSHIFT}$ von Hessen bekannt.

Sheet1

Compound nouns for stress patterns

	Story			Story	
	shift	**clash**		**noshift**	**lapse**
Bahnzeitschrift	101	201	Modezeitschrift	207	107
Bankkaufmann	203	103	Handelskaufmann	107	207
Baugrundstück	205	105	Weidegrundstück	212	112
Busbahnhof	117	217	Reisebahnhof	116	216
Busfahrschein	108	208	Fährenfahrschein	209	109
Chefvolkswirt	102	202	Landesvolkswirt	105	205
Feldhandball	217	117	Hallenhandball	118	218
Filzhausschuh	212	112	Lederhausschuh	111	211
Flachbildschirm	201	101	Plasmabildschirm	208	108
Großbaumarkt	202	102	Profibaumarkt	215	115
Hauptbahnhof	208	108	Güterbahnhof	110	210
Hauptwohnsitz	119	219	Nebenwohnsitz	106	206
Raumputzplan	220	120	Klinikputzplan	119	219
Herzstillstand	219	119	Atemstillstand	218	118
Holzspielzeug	105	205	Plastikspielzeug	112	212
Kraftfahrzeug	104	204	Wasserfahrzeug	216	116
Kreishauptstadt	113	213	Bundeshauptstadt	211	111
Kunstdenkmal	209	109	Kriegerdenkmal	220	120
Kurzparkplatz	215	115	Mofaparkplatz	204	104
Landgasthof	213	113	Wandergasthof	206	106
Messwerkzeug	120	220	Profiwerkzeug	219	119
Notfahrplan	116	216	Regelfahrplan	210	110
Rostbratwurst	109	209	Rinderbratwurst	202	102
Salzbergwerk	103	203	Silberbergwerk	214	114
Schnellkochtopf	207	107	Profikochtopf	101	201
Sportflugzeug	210	110	Wasserflugzeug	109	209
Staatshaushalt	206	106	Bundeshaushalt	201	101
Stadtrundfahrt	107	207	Alsterrundfahrt	203	103
Stammmannschaft	104	204	Frauenmannschaft	104	204
Startbildschirm	118	218	Rechnerbildschirm	115	215
Startzeitpunkt	214	114	Antrittszeitpunkt	103	203
Stoffhandtuch	112	212	Badehandtuch	217	117
Strahltriebwerk	110	210	Kolbentriebwerk	113	213
Tatzeitraum	211	111	Krisenzeitraum	114	214
Textbaustein	218	118	Werbebaustein	120	220
Tischfußball	115	215	Hallenfußball	117	217
Triebfahrwerk	216	116	Schienenfahrwerk	213	113
Wachsmalstift	114	214	Kohlemalstift	205	105
Waldschwimmbad	106	206	Hallenschwimmbad	102	202

Page 1

Kandylaki 2015

Experimental procedure

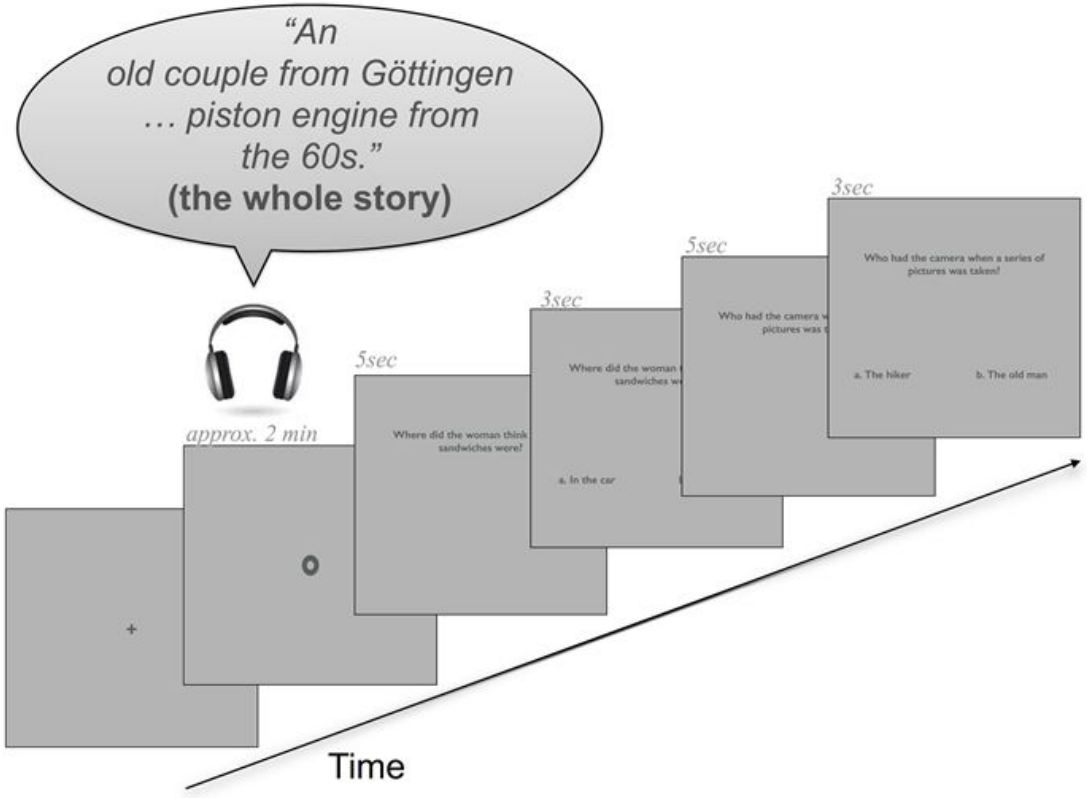
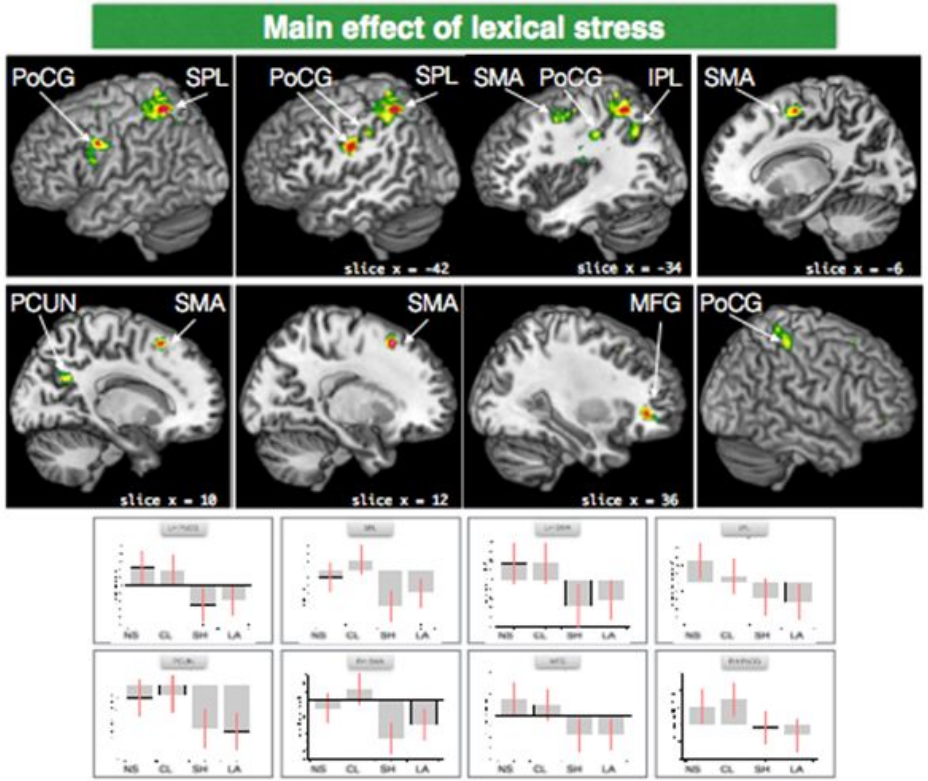
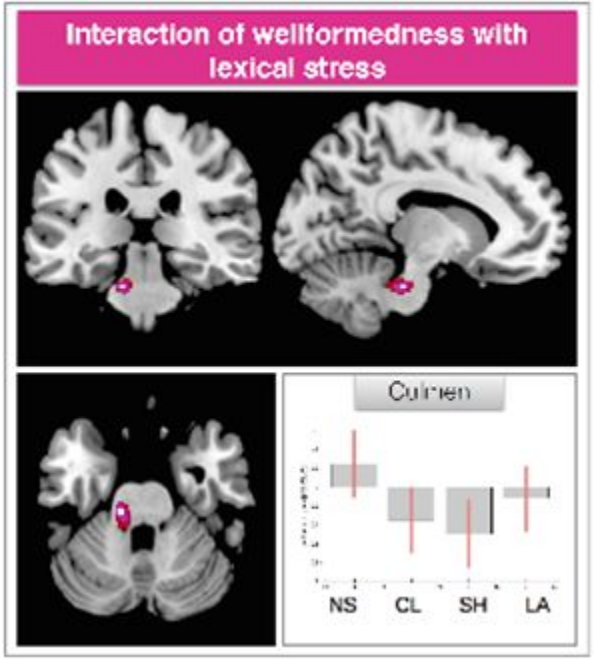


Figure from Kandylaki et al. 2015

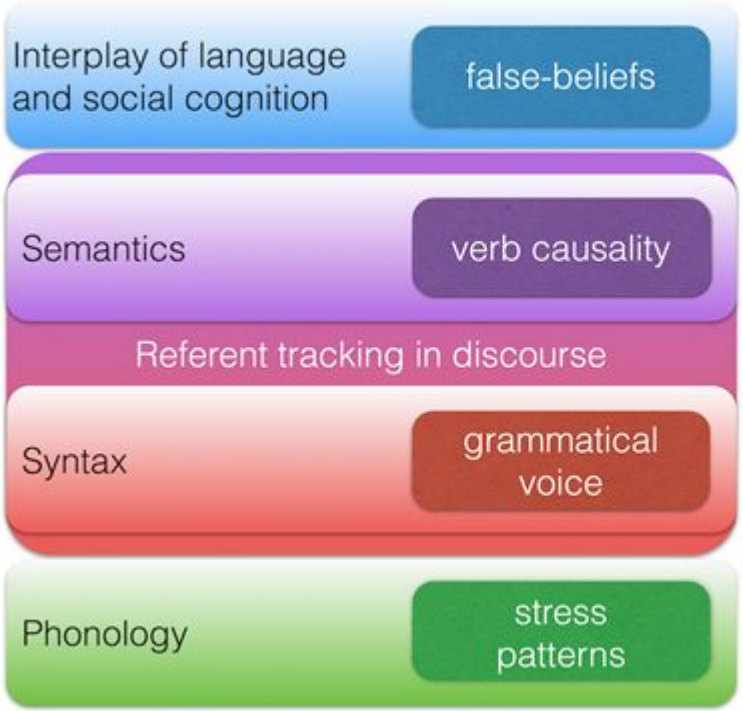
Results





Kandylaki et al. 2017, *JoCN*

Interpretation



- processing of linguistic rhythm in natural context
- absence of task directed to the prosodic features
- findings connect rhythmical processing in language with:
  1. sensorimotor network of speech perception (Hickok, Houde, & Rong, 2011)
  2. domain-independent timing perception (Schwartze et al., 2012)

Kandylaki et al. 2017, *JoCN*

Interlude

Okay, so language comprehension uses existing mechanisms, such as the one for timing
And that is realised in the brain also in motor areas

Does that mean that if someone trains these areas as part of a rhythm mechanism, they might influence their language comprehension?

How to approach beat extraction in a naturalistic experiment?

- Stimuli and Procedure
- Quantification of rhythm
- Tested population
- The Rhythm Network nodes

Stimuli - rhythmically regular vs. irregular

- Stories: speech rhythm not regular
- Poems: metered speech, rhythmic regularity

Speech comprehension experiment

Wir können jederzeit anfangen.
Einfach auf eine Taste drücken.

Trial

2-4 min

+

Was sagen die Großeltern als sie zu Besuch kommen?

a. Dass sie beim vorbereiten helfen möchten

b. Dass sie zu spät sind

Wie fühlt sich die Protagonistin nach der Bescherung?

a. Glücklich

b. Kaputt

time

Das war's!
Danke für die Teilnahme!

How to approach beat extraction in a naturalistic experiment?

- Stimuli and Procedure ✔
- Quantification of rhythm
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Audio content analysis for the speech signal

Audio content analysis: Music Genre Classification

We assume that the rhythmic content of a sound can be captured through the signal-inherent periodicities and their properties.

According to phonetics:

1. Amplitude - loudness denotes the stresses, intonation
2. Pitch - F0, speech prosody
3. Spectral changes - sound texture and timbre (tonal/noisy)

Lykartsis & Weinzierl, 2015

Novelty functions / speech features

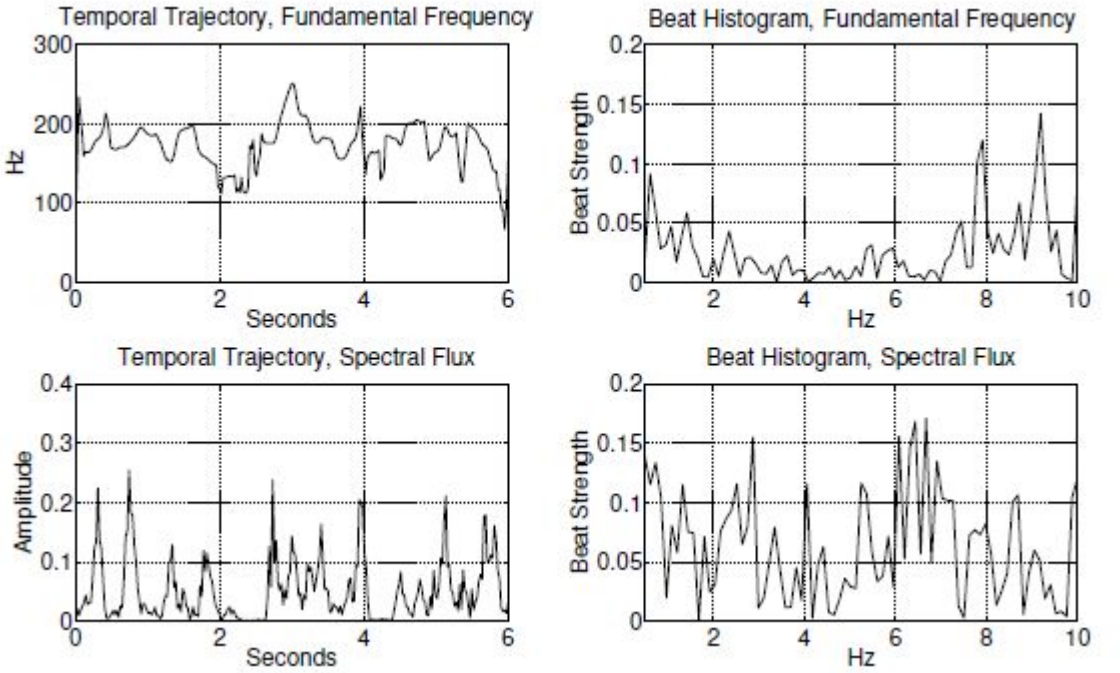
Beat histogram (on basis of the trajectory of various relevant signal quantities over time)

1. RMS energy
2. Fundamental frequency (F0)
3. Spectral Flux (general spectral change)
4. Spectral Flatness (tonalness / noisiness)
5. Spectral Centroid (spectral centre-of-weight)

We need to test the features for our stimuli

Lykartsis & Weinzierl, 2015

Features



Gestern war ich in einem Selbsterfahrungskurs. Ich bin mir nicht wirklich sicher, ob es mir gefallen hat

Lykartsis & Weinzierl, 2015

Theoretical beat

We combine the (normalized) features into a new feature

33% RMS Energy - loudness
33% F0 - pitch
33% Spectral Flux - higher for voiced parts

We call this new feature theobeat

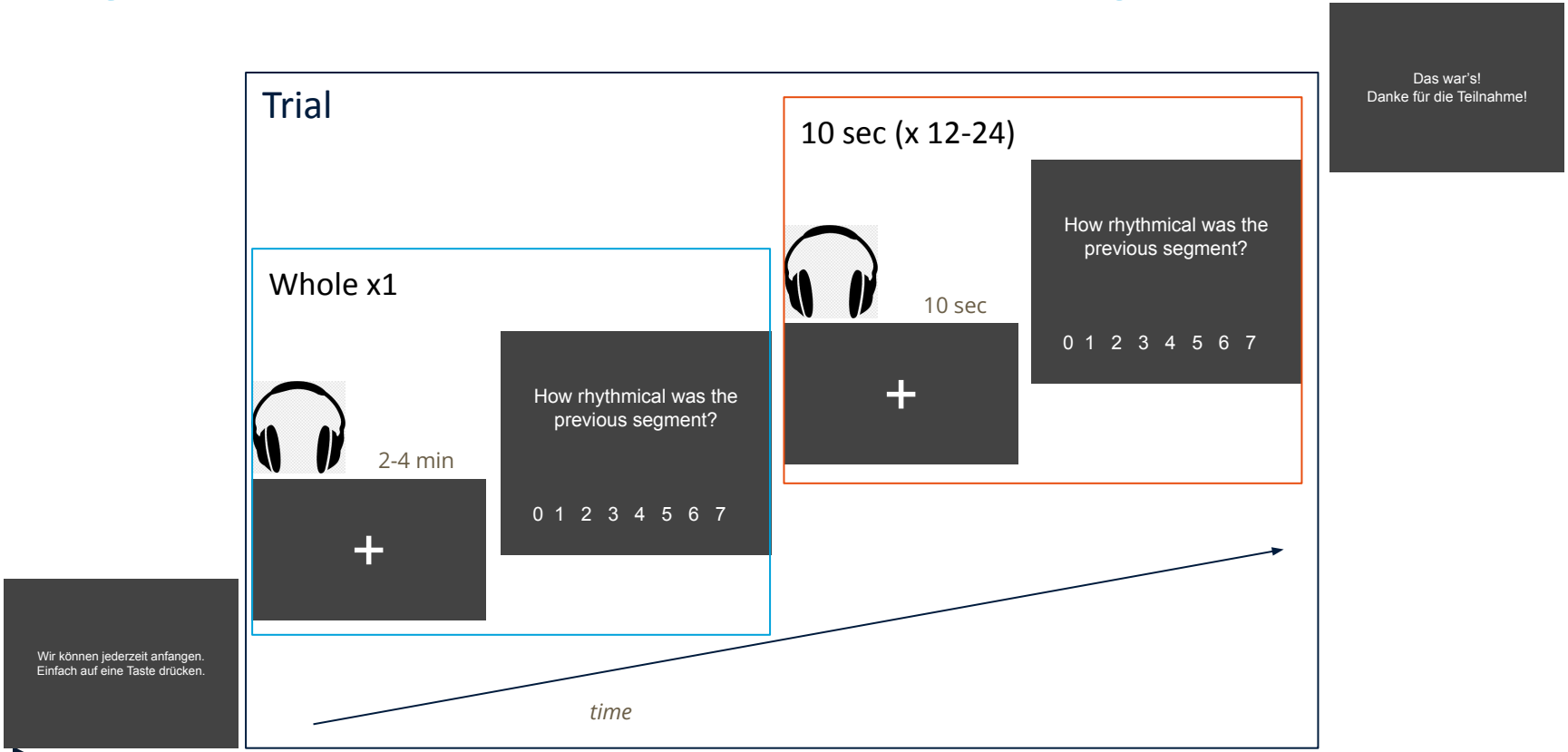
Testing the features & design

Computationally
Extracting the features for our stimuli and statistically analysing them by category

Behaviorally
Rhythm evaluations of the stimuli and statistical analysis of the evaluations

		Condition	
		Poem - metered speech	Story - non metered speech
Length	Whole audio	Poem Whole	Story Whole
	10 sec chunks	Poem 10sec	Story 10sec

Rhythm evaluation - behavioral experiment



Kandylaki, Utroša-Škerjanec, & Kotz, in preparation

Evaluation scale

Response	German Original	English Translation
0	stille	silence
1	gar nicht rhythmisch	not rhythmic at all
2	kaum rhythmisch	barely rhythmic
3	ein wenig rhythmisch	a little rhythmic
4	mittelmäßig rhythmisch	moderately rhythmic
5	gut rhythmisch	well rhythmic
6	sehr gut rhythmisch	very well rhythmic
7	perfekt rhythmisch	perfectly rhythmic

Kandylaki, Utroša-Škerjanec, & Kotz, in preparation

Hypotheses - behavioral

- Poems will be rated as more rhythmical than stories
- This would be for the whole but not necessarily for the 10sec (because of the variability)
- Poems will differ from stories based on their rhythm-related features (RMS Energy, F0, and Spectral Flux)

Kandylaki, Utroša-Škerjanec, & Kotz, in preparation

Hypotheses - computational

Only the features related to beat (RMS Energy, F0, Spectral Flux, and Theobeat) will differ significantly between poems and stories.

The other features will not be significantly different between poems and stories.

The variability of the responses will be bigger in chunks than in whole audio.

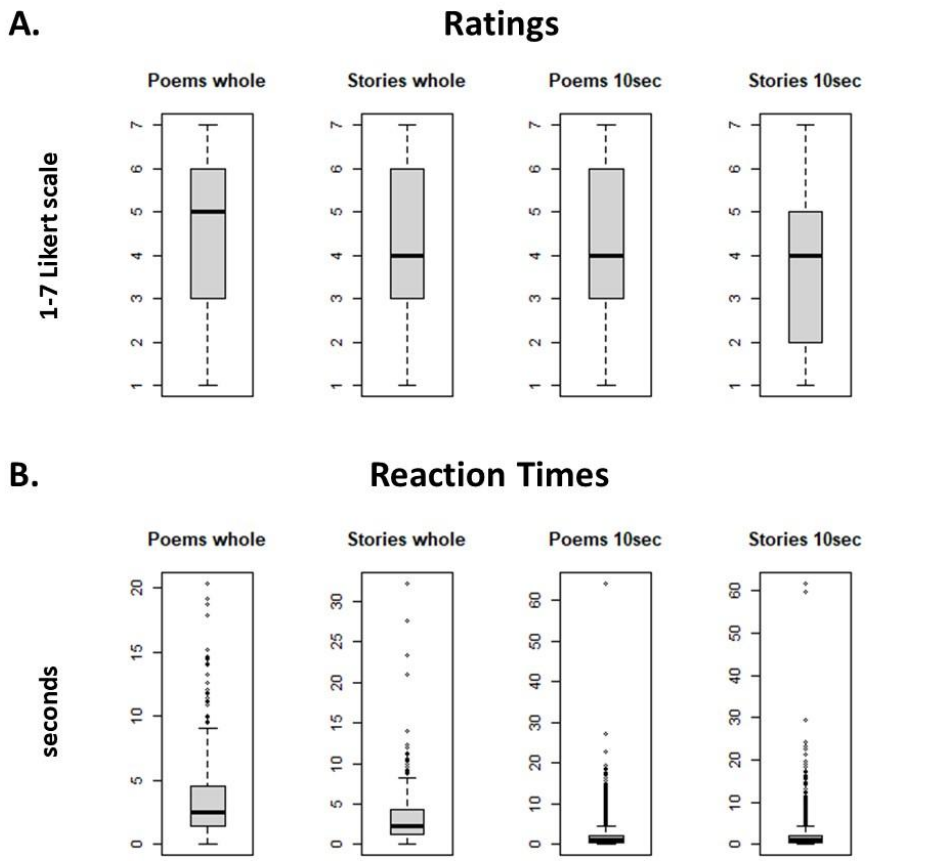
Kandylaki, Utroša-Škerjanec, & Kotz, in preparation

Behavioral results

Ratings - as expected:

- Whole poems rated higher than whole stories
- In the 10sec segments the means are very close but the data is skewed differently

RTs longer for whole poems than whole stories, 10sec segments similar RTs



Kandylaki, Utroša-Škerjanec, & Kotz, in preparation

Referential statistics - Scoring

Logistic regression - Mixed effects models, fitted with `clmm()` from R package ‘ordinal’

Scoring

Null: Scoring ~ RI item + RI participant

ME: Scoring ~ Condition + Length + RI item + RI participant

INT: Scoring ~ Condition * Length + RI item + RI participant

RI: random intercept, ME: main effect(s), INT: interaction

Kandylaki, Utroša-Škerjanec, & Kotz, in preparation

Results - stepwise comparisons for Scoring

Model comparisons with `anova(m1,m2)`

Null vs. **ME** ***

ME vs. INT -

AIC values N: 44274, **ME: 44255**, INT: 44257

Both measures point to the main effects model as the best fit, but only the Length factor was significant within the model (p <.001)

→ The Scoring values are best explained as a **main effect of length**

Kandylaki, Utroša-Škerjanec, & Kotz, in preparation

Referential statistics - RTs

Linear regression - Mixed effects models, fitted with `lmer()` from R package 'lme4'

RTs

Null: RT ~ RI item + RI participant

ME: RT ~ Condition + Length + RI item + RI participant

INT: RT ~ Condition * Length + RI item + RI participant

RI: random intercept, ME: main effect(s), INT: interaction

Kandylaki, Utroša-Škerjanec, & Kotz, in preparation

Results - stepwise comparisons for RTs

Model comparisons with `anova(m1,m2)`

Null vs. **ME** ***

ME vs. INT -

AIC values N: 56009, **ME: 55514**, INT: 55516

Both measures point to the main effects model as the best fit

→ The RTs are (also) best explained as **main effects of rhythmic regularity and length** (the main effects of rhythmic regularity and length are significant)

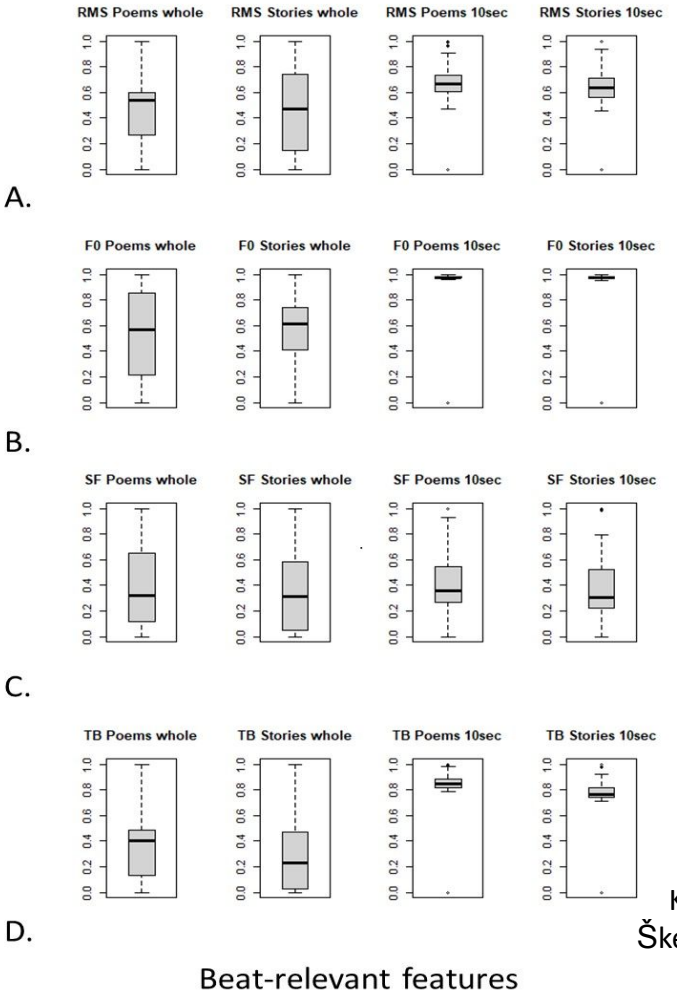
Kandylaki, Utroša-Škerjanec, & Kotz, in preparation

Computational results for beat-relevant features

A. RMS energy
B. F0/Pitch
C. Spectral Flux
D. Theobeat

Theobeat shows the expected pattern, and similar to the behavioral results

The composition is meaningful



Kandylaki, Utroša-Škerjanec, & Kotz, in preparation

Referential statistics - same procedure for all features

Linear regression - Mixed effects models, fitted with `lmer()` from R package 'lme4'

Computational

Null model: [feature] ~ RI item

ME: [feature] ~ Condition + Length + RI item

INT: [feature] ~ Condition * Length + RI item

RI: random intercept, ME: main effect(s), INT: interaction

Kandylaki, Utroša-Škerjanec, & Kotz, in preparation

AIC values for the beat-relevant features

	Null	ME	INT
RMS Energy	3714.8	**3658.4**	3660.4
F0 / Pitch	544.2	**518.2**	520.2
Spectral Flux	11129.4	**10572.6**	10574.6
Theobeat	544.2	**518.2**	520.2

Results stepwise comparisons - beat-relevant features

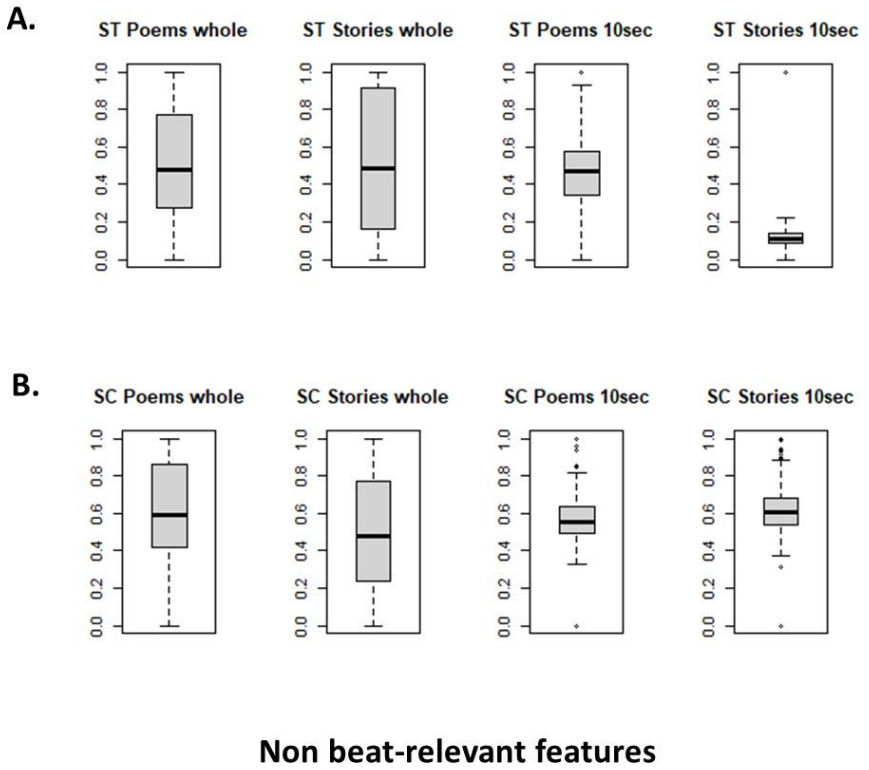
Model comparisons with `anova(m1,m2)`
RMS Energy, F0, Spectral Flux, Theobeat
Null vs. ME ***
ME vs INT -

Within the main effects model for each feature:
RMS, F0, Theobeat: Only rhythmic regularity significant (p <.001)
Spectral Flux: Only Length significant (p <.001)

The beat-relevant features differed as a function of **main effects of rhythmic regularity or length**

Computational results for non beat-relevant features

A. Spectral Flatness - whole - no differences, 10 sec stories scored much lower
B. Spectral Centroid - no big differences



Non beat-relevant features

AIC values for the non beat-relevant features

		Null	ME	INT
Non beat-relevant	Spectral Centroid	13420.6	13111.6	**13103.1**
	Spectral Flatness	137.8	**127.4**	129.4

Results stepwise comparisons - non beat-relevant features

Spectral Centroid		Spectral Flatness	
Null vs. ME	***	Null vs. ME	***
ME vs INT	**	ME vs INT	-
-> INT		-> ME	

SC: interaction effect significant (p = .001)
SFlat: no main effects reached significance (p >.1)

The non beat-relevant features showed a **mixed pattern**

Summary & Discussion - Behavioral

The Scoring results did not show an effect of rhythmic regularity

Possibly the task was too meta-cognitive, asking for an evaluation instead of recording spontaneous movement while listening to the rhythmic stimuli.

Maybe the difference is earlier in the system, than in the decision of evaluation and needs to be approached with on-line and higher temporal resolution methods, such as EEG.

Summary & Discussion - Computational

The periodicities we quantified did differ between poems and stories.

The rhythm of the speech signal was not composed by only the beat-relevant features, but also by the non-beat relevant ones, such as Spectral Centroid.

There is more to rhythm than just the beat - this is shown in this naturalistic experiment with stories (rich context).

Take home for future studies

In the EEG study which we have collected data for, we will not only focus on the Theobeat as a quantification of rhythmic regularity.

How to approach beat extraction in a naturalistic experiment?

- Stimuli and Procedure ✔
- Quantification of rhythm ✔
- Tested population
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Tested population

OPERA hypothesis (Overlap, Precision, Emotion, Repetition, Attention):
Benefits of musical training on the neural encoding of speech - based on adaptive plasticity

Who has a trained rhythm network?

https://www.thomann.de/blog/en/quiz-9-types-musicians-one/

Patel, 2011

How to approach beat extraction in a naturalistic experiment?

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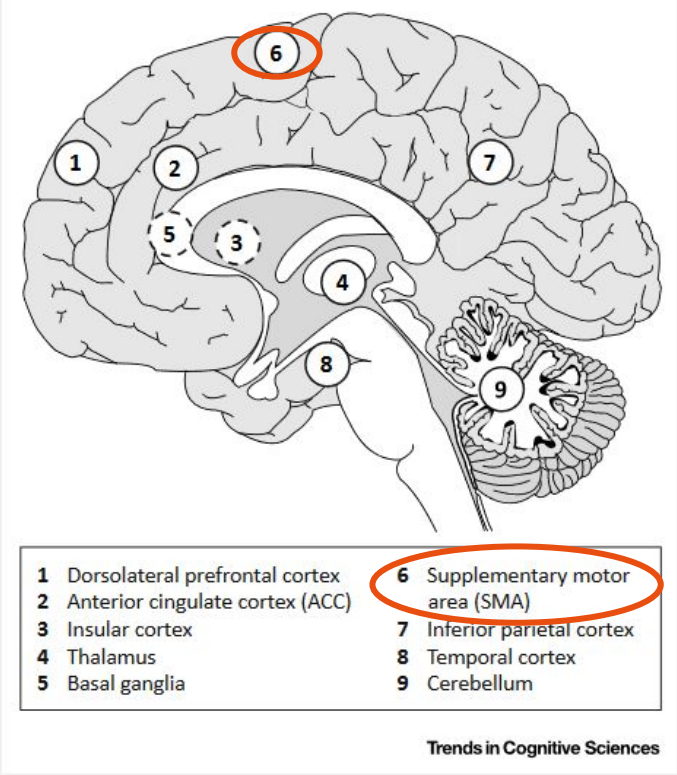
The rhythm network

Cortico-subcortical brain network for time and rhythm processing

SMA involved in **beat extraction**

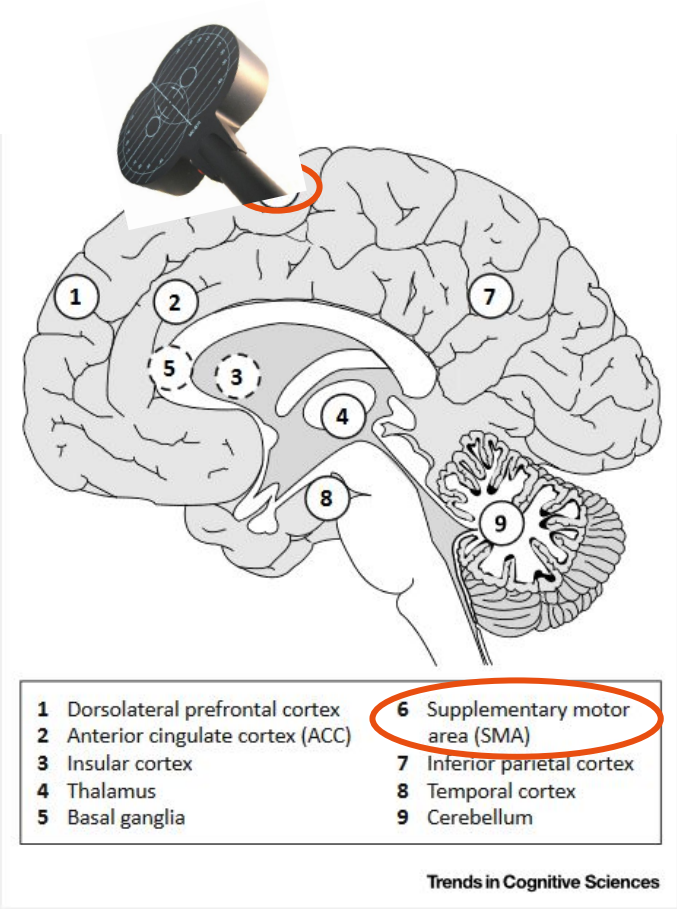
the cognitive process by which the frequency and phase of some external periodic signal are inferred by a listener



Kotz, Ravignani, & Fitch, 2018, TICS

Targeting the supplementary motor area (SMA)

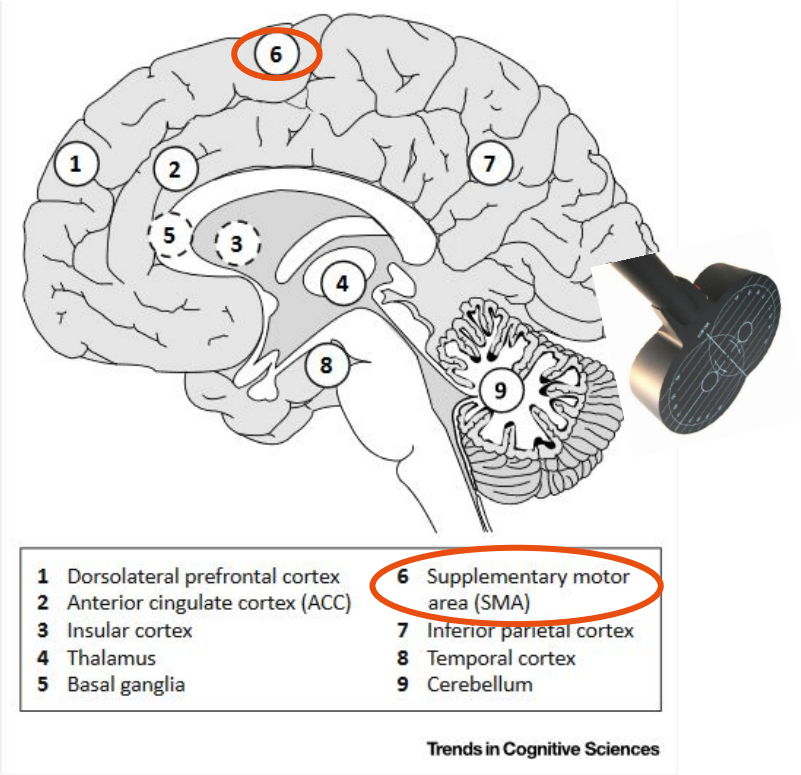
Expected that musicians will respond the same as non musicians when their SMA is inhibited



Kotz, Ravignani, & Fitch, 2018, TICS

Adding a control site - Early Visual Cortex (EVC)

To exclude possible explanations that it is the stimulation in general and not the stimulation in the SMA in specific causing the differences



Speech comprehension experiment

Das war's!
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2-4 min

+

Was sagen die Großeltern als sie zu Besuch kommen?

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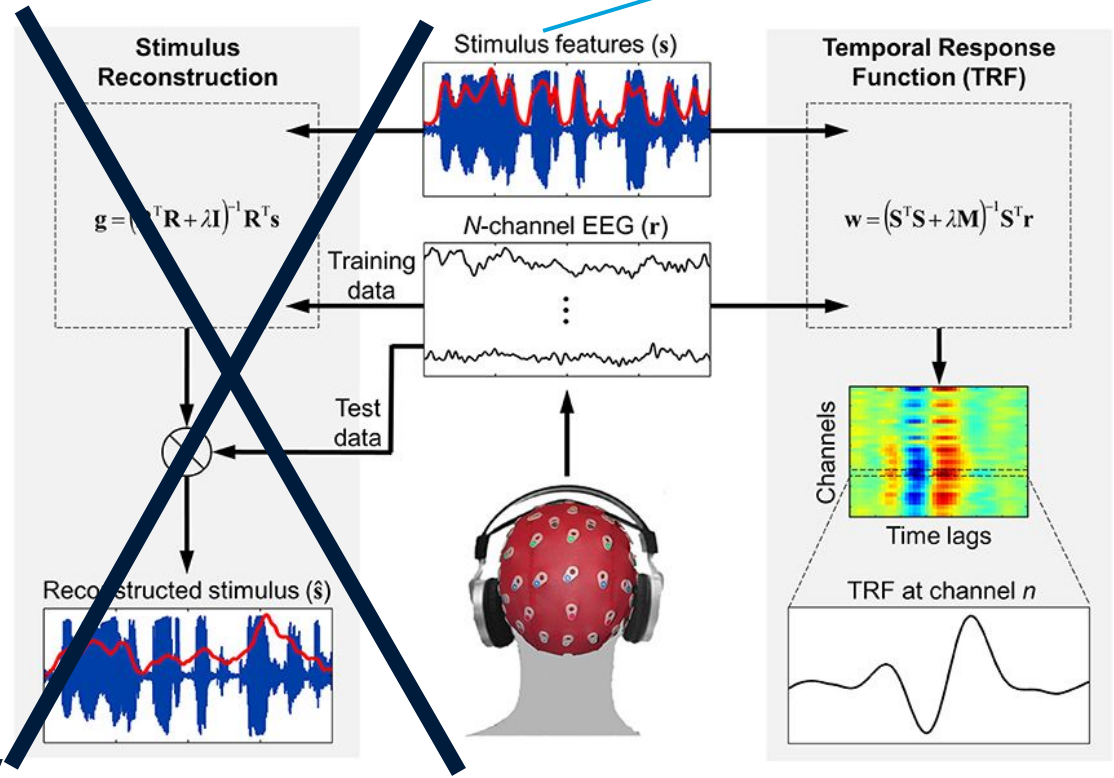
- The Rhythm Network nodes ✔

Modeling of the data - work in progress

Theobeat



Thank you for inviting me!

Keep in touch with the
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Maastricht University

Quantification of beat from the speech signal

- Early approaches: annotations between consonants, vowels, stresses and calculating the the distance between these (ΔC, %V , nPVI)
- Newer approaches: extract rhythmic quantities directly from the acoustic signal, specifically by **extracting salient periodicities and their characteristics from its amplitude envelope**
- Language Identification (LID): used automatic segmentation of the speech signal in pseudosyllables and extracted statistical features describing energy and fundamental frequency

Lykartsis & Weinzierl, 2015

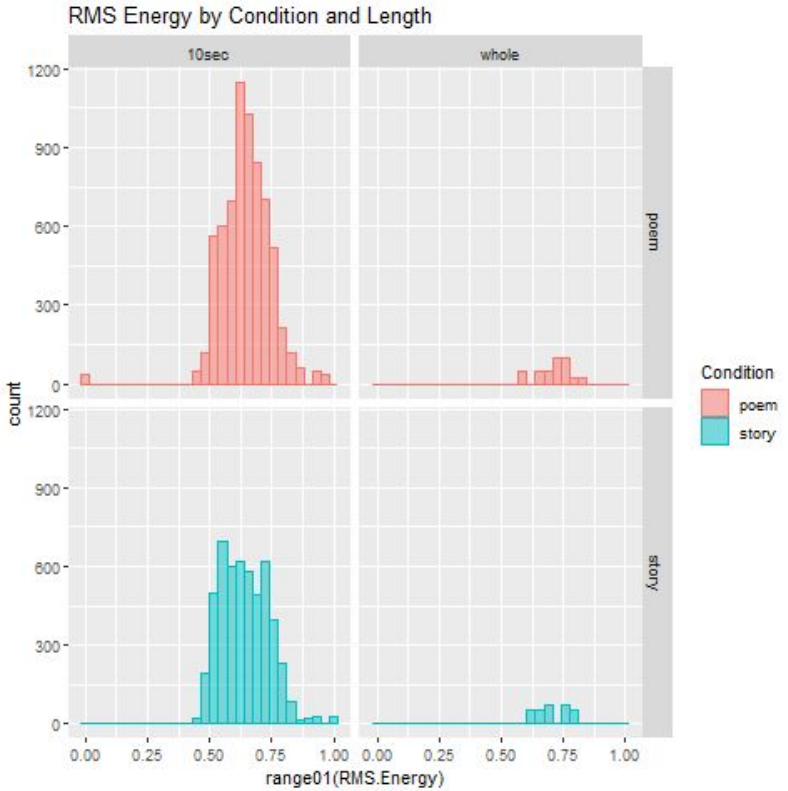
In this approach

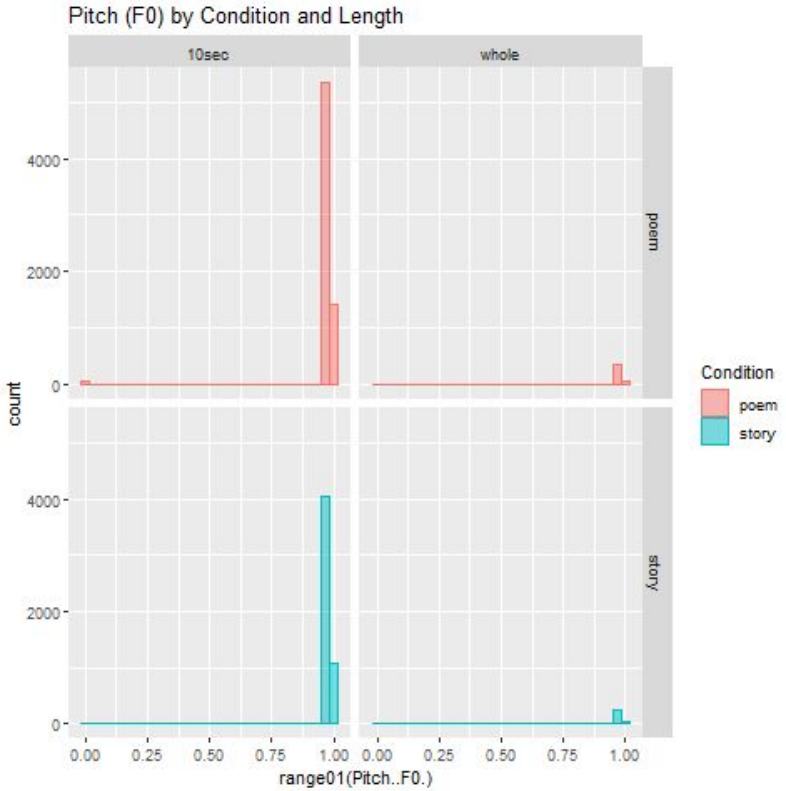
The focus is shifted on **quantities in the speech signal** rather than on the regularities of more linguistically defined speech elements

Same quantification can be used for different languages independently of their rhythm class.

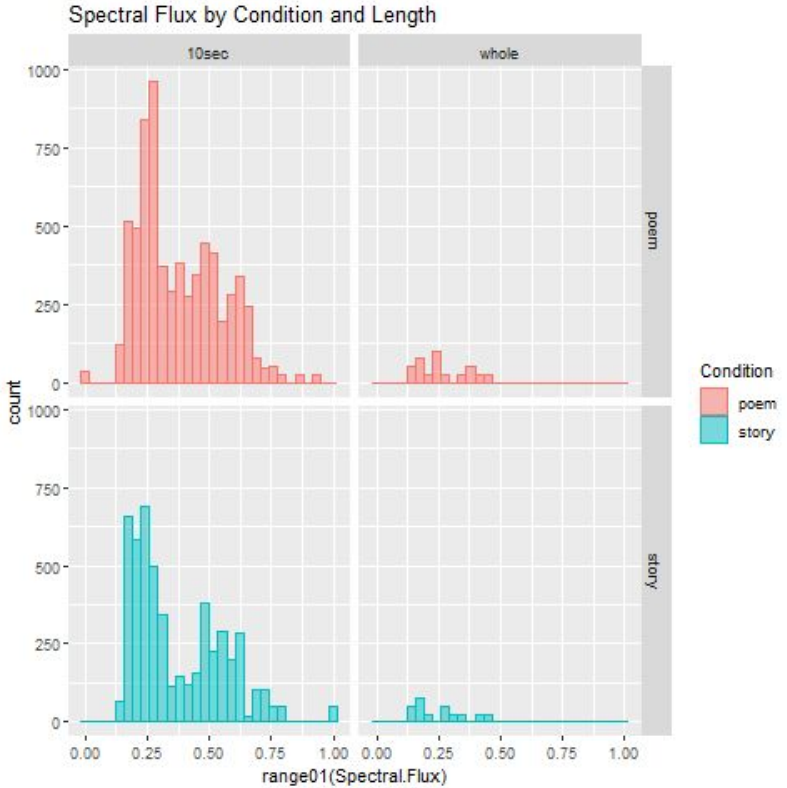
Lykartsis & Weinzierl, 2015

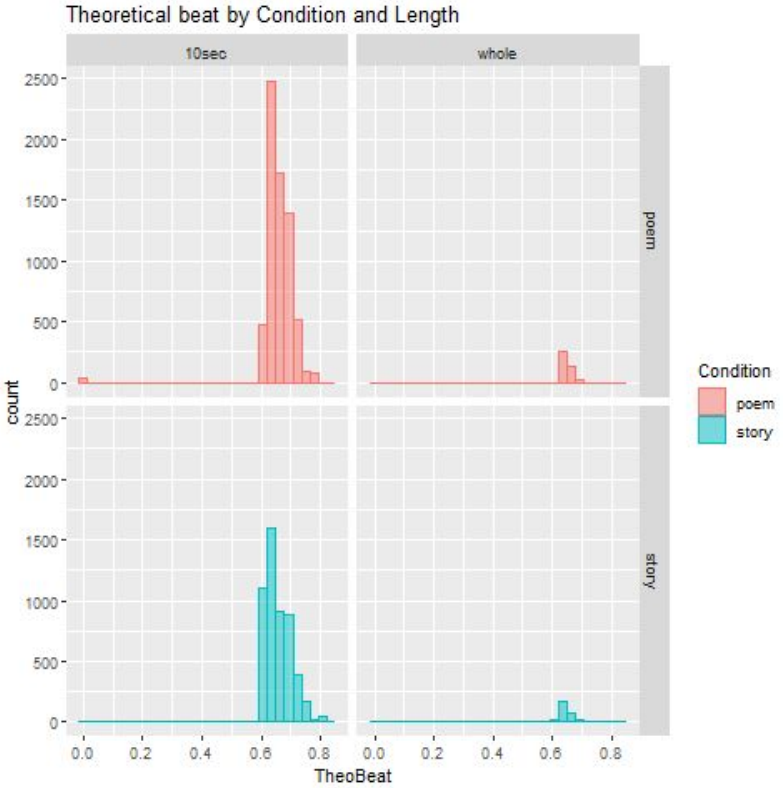
Results - computational - RMS Energy, F0





Results - computational - Spectral Flux, Theobeat





Results - behavioral - Scoring