

# Looking for the Phonological Mapping Negativity (in all the wrong places)

**Massimiliano Canzi** `massimiliano.canzi@uni-konstanz.de`

June 24 2021

## Section 1

### Introduction

# Introduction

Four years ago...

# Introduction

Can event-related potential data inform information flow order in speech perception?

# Introduction

Can event-related potential data inform information flow order in speech perception? i.e. what the extent of top-down mediation is during speech perception.

# Event-related potentials

Event-related potentials (ERP) are measured brain responses that are direct result of a **sensory**, **cognitive** or motor event (Luck 2005)

# Event-related potentials

Event-related potentials (ERP) are measured brain responses that are direct result of a **sensory**, **cognitive** or motor event (Luck 2005)

Event-related potential components are measured with electroencephalography (EEG) equipment.

# Introduction

Top-down vs bottom-up in speech perception:



# Introduction

Top-down vs bottom-up in speech perception:

- Interactive models of speech perception e.g. **TRACE** (McClelland & Elman 1986)

# Introduction

Top-down vs bottom-up in speech perception:

- Interactive models of speech perception e.g. **TRACE** (McClelland & Elman 1986)
- Feed-forward / modular models of speech perception e.g. **Cohort** (Marslen-Wilson 1984)

Introduction

oooo●oooooooooooooooo

Methods

oooooooo

Experiment 1

oooooooooooooooo

Experiment 2

oooooooooooo

General Discussion

ooooooo

# Introduction

# Introduction

- Elman, J. L., & McClelland, J. L. (1988). Cognitive penetration of the mechanisms of perception: Compensation for coarticulation of lexically restored phonemes. *Journal of Memory and Language*, 27(2), 143-165.

# Introduction

- Elman, J. L., & McClelland, J. L. (1988). Cognitive penetration of the mechanisms of perception: Compensation for coarticulation of lexically restored phonemes. *Journal of Memory and Language*, 27(2), 143-165.
- Pitt, M. A., & McQueen, J. M. (1998). Is compensation for coarticulation mediated by the lexicon? *Journal of Memory and Language*, 39, 347–370.

# Introduction

- Elman, J. L., & McClelland, J. L. (1988). Cognitive penetration of the mechanisms of perception: Compensation for coarticulation of lexically restored phonemes. *Journal of Memory and Language*, 27(2), 143-165.
- Pitt, M. A., & McQueen, J. M. (1998). Is compensation for coarticulation mediated by the lexicon? *Journal of Memory and Language*, 39, 347–370.
- Magnuson et al. (2003). Lexical effects on compensation for coarticulation: **The ghost of Christmash past**. *Cognitive Science*, 27(2), 285-298.

# Introduction

- Elman, J. L., & McClelland, J. L. (1988). Cognitive penetration of the mechanisms of perception: Compensation for coarticulation of lexically restored phonemes. *Journal of Memory and Language*, 27(2), 143-165.
- Pitt, M. A., & McQueen, J. M. (1998). Is compensation for coarticulation mediated by the lexicon? *Journal of Memory and Language*, 39, 347–370.
- Magnuson et al. (2003). Lexical effects on compensation for coarticulation: **The ghost of Christmash past**. *Cognitive Science*, 27(2), 285-298.
- McQueen, J. M. (2003). **The ghost of Christmas future: didn't scrooge learn to be good?**: Commentary on Magnuson et al. (2003). *Cognitive Science*, 27(5), 795-799.

# Introduction

- Elman, J. L., & McClelland, J. L. (1988). Cognitive penetration of the mechanisms of perception: Compensation for coarticulation of lexically restored phonemes. *Journal of Memory and Language*, 27(2), 143-165.
- Pitt, M. A., & McQueen, J. M. (1998). Is compensation for coarticulation mediated by the lexicon? *Journal of Memory and Language*, 39, 347–370.
- Magnuson et al. (2003). Lexical effects on compensation for coarticulation: **The ghost of Christmash past**. *Cognitive Science*, 27(2), 285-298.
- McQueen, J. M. (2003). **The ghost of Christmas future: didn't scrooge learn to be good?**: Commentary on Magnuson et al. (2003). *Cognitive Science*, 27(5), 795-799.
- McQueen, et al. (2009). No lexical–prelexical feedback during speech perception or: **Is it time to stop playing those Christmas tapes?**. *Journal of Memory and Language*, 61(1), 1-18.



# Elman & McClelland (1988)

Compensation for coarticulation: (Mann & Repp 1981)

# Elman & McClelland (1988)

Compensation for coarticulation: (Mann & Repp 1981)

- /t-k/ perceived more often as /k/ following /s/

Ganong effect (Ganong 1980)

# Elman & McClelland (1988)

Compensation for coarticulation: (Mann & Repp 1981)

- /t-k/ perceived more often as /k/ following /s/
- /t-k/ perceived more often as /t/ following /ʃ/

Ganong effect (Ganong 1980)

# Elman & McClelland (1988)

Compensation for coarticulation: (Mann & Repp 1981)

- /t-k/ perceived more often as /k/ following /s/
- /t-k/ perceived more often as /t/ following /ʃ/

Ganong effect (Ganong 1980)

- Ambiguous phonemes are solved more often with the choice that makes a word vs. a non-word

# Elman & McClelland (1988)

Compensation for coarticulation: (Mann & Repp 1981)

- /t-k/ perceived more often as /k/ following /s/
- /t-k/ perceived more often as /t/ following /ʃ/

Ganong effect (Ganong 1980)

- Ambiguous phonemes are solved more often with the choice that makes a word vs. a non-word
- e.g. Christma/s-ʃ/ more often solved as Christma/s/.

# Elman & McClelland (1988)

Compensation for coarticulation: (Mann & Repp 1981)

- /t-k/ perceived more often as /k/ following /s/
- /t-k/ perceived more often as /t/ following /ʃ/

Ganong effect (Ganong 1980)

- Ambiguous phonemes are solved more often with the choice that makes a word vs. a non-word
- e.g. Christma/s-ʃ/ more often solved as Christma/s/.
- Effect stronger at phoneme boundary.

# Elman & McClelland (1988)

Christma/s-ʃ/ /t-k/capes

# Elman & McClelland (1988)

Christma/**s-f**/ /**t-k**/capes

Cool, huh?



# Introduction

Can event-related potential data inform information flow order in speech perception?

# Introduction

Can event-related potential data inform information flow order in speech perception? i.e. what the extent of top-down mediation is during speech perception.

# Event-related potentials

ERP (and EEG) offer unparalleled temporal resolution,

# Event-related potentials

ERP (and EEG) offer unparalleled temporal resolution, opening a direct window into cognitive processes of online language processing and speech perception.

# Event-related potentials

ERP (and EEG) offer unparalleled temporal resolution, opening a direct window into cognitive processes of online language processing and speech perception.

The original goal of my thesis was that to **design** a handful of **ERP experiments to investigate lexical feedback** and top-down processes of speech perception.

# Event-related potentials

ERP (and EEG) offer unparalleled temporal resolution, opening a direct window into cognitive processes of online language processing and speech perception.

The original goal of my thesis was that to **design** a handful of **ERP experiments to investigate lexical feedback** and top-down processes of speech perception. But how?

# Event-related potentials

- Mismatch Negativity (MMN)

\* Originanly named Phonological Mismatch Negativity

# Event-related potentials

- Mismatch Negativity (**MMN**)
- Phonological Mapping\* Negativity (**PMN**)

\* Originanly named Phonological Mismatch Negativity



# Event-related potentials

- Mismatch Negativity (**MMN**)
- Phonological Mapping\* Negativity (**PMN**)
- **N400**

\* Originanly named Phonological Mismatch Negativity

# Event-related potentials

- Mismatch Negativity (**MMN**)
- Phonological Mapping\* Negativity (**PMN**)
- **N400**
- **P600**

\* Originanly named Phonological Mismatch Negativity

# MMN

The mismatch negativity (MMN) is a cross-sensorial ERP component often observed in frontocentral regions of the scalp between 150 and 250 ms post stimulus onset

# MMN

The mismatch negativity (MMN) is a cross-sensorial ERP component often observed in frontocentral regions of the scalp between 150 and 250 ms post stimulus onset

The mismatch negativity reflects the perception of a deviant stimulus in a sequence of standard stimuli (e.g. Garrido et al., 2009)

# MMN

The mismatch negativity (MMN) is a cross-sensorial ERP component often observed in frontocentral regions of the scalp between 150 and 250 ms post stimulus onset

The mismatch negativity reflects the perception of a deviant stimulus in a sequence of standard stimuli (e.g. Garrido et al., 2009)

In the auditory domain, a deviant stimulus can be identified by differences in pitch, duration, stress and frequency range (Erlbeck et al., 2014)

# MMN

However, the MMN was also found to be sensitive to phonological mapping (Pulvermuller 2001)

# MMN

However, the MMN was also found to be sensitive to phonological mapping (Pulvermuller 2001)

- MMN to the presentation of mismatching Finnish words

# MMN

However, the MMN was also found to be sensitive to phonological mapping (Pulvermuller 2001)

- MMN to the presentation of mismatching Finnish words
- No MMN in control group



# N400

The N400 (Kutas & Hillyard 1980) is part of the normal brain response to words and other meaningful stimuli.

# N400

The N400 (Kutas & Hillyard 1980) is part of the normal brain response to words and other meaningful stimuli.

nurse

# N400

The N400 (Kutas & Hillyard 1980) is part of the normal brain response to words and other meaningful stimuli.

nurse doctor

# N400

The N400 (Kutas & Hillyard 1980) is part of the normal brain response to words and other meaningful stimuli.

nurse doctor |

# N400

The N400 (Kutas & Hillyard 1980) is part of the normal brain response to words and other meaningful stimuli.

nurse doctor | pizza

# N400

The N400 (Kutas & Hillyard 1980) is part of the normal brain response to words and other meaningful stimuli.

nurse doctor | pizza pineapple

# N400

The N400 (Kutas & Hillyard 1980) is part of the normal brain response to words and other meaningful stimuli.

nurse doctor | pizza pineapple

- Other paradigms include cloze-probability mismatch (e.g. Connolly and Phillips 1994)

# Phonological Mapping Negativity

The Phonological Mapping (or Mismatch) Negativity, **PMN** is an event-related potential component hypothesized to index phonological mismatch and mapping



# Phonological Mapping Negativity

The Phonological Mapping (or Mismatch) Negativity, **PMN** is an event-related potential component hypothesized to index phonological mismatch and mapping (e.g. Connolly and Phillips 1994; Connolly et al. 2001)

# Phonological Mapping Negativity

However, while some studies (e.g. Connolly and Phillips 1994) have linked the PMN to phonological mapping during the lexical selection stage of speech perception..

# Phonological Mapping Negativity

However, while some studies (e.g. Connolly and Phillips 1994) have linked the PMN to phonological mapping during the lexical selection stage of speech perception..

Others (e.g. Newman et al.) report that the PMN is a **marker of acoustic and pre-lexical information**.

# Connolly and Phillips (1994)

Event-Related Potential Components Reflect Phonological and Semantic Processing of the Terminal Word of Spoken Sentences:

# Connolly and Phillips (1994)

Event-Related Potential Components Reflect Phonological and Semantic Processing of the Terminal Word of Spoken Sentences:

- The piano is out of

# Connolly and Phillips (1994)

Event-Related Potential Components Reflect Phonological and Semantic Processing of the Terminal Word of Spoken Sentences:

- The piano is out of tune

# Connolly and Phillips (1994)

Event-Related Potential Components Reflect Phonological and Semantic Processing of the Terminal Word of Spoken Sentences:

- The piano is out of tune (no mismatch)

# Connolly and Phillips (1994)

Event-Related Potential Components Reflect Phonological and Semantic Processing of the Terminal Word of Spoken Sentences:

- The piano is out of tune (no mismatch)
- The piano is out of



# Connolly and Phillips (1994)

Event-Related Potential Components Reflect Phonological and Semantic Processing of the Terminal Word of Spoken Sentences:

- The piano is out of tune (no mismatch)
- The piano is out of tuna

# Connolly and Phillips (1994)

Event-Related Potential Components Reflect Phonological and Semantic Processing of the Terminal Word of Spoken Sentences:

- The piano is out of tune (no mismatch)
- The piano is out of tuna (N400)

# Connolly and Phillips (1994)

Event-Related Potential Components Reflect Phonological and Semantic Processing of the Terminal Word of Spoken Sentences:

- The piano is out of tune (no mismatch)
- The piano is out of tuna (N400)
- The piano is out of

# Connolly and Phillips (1994)

Event-Related Potential Components Reflect Phonological and Semantic Processing of the Terminal Word of Spoken Sentences:

- The piano is out of tune (no mismatch)
- The piano is out of tuna (N400)
- The piano is out of pizza

# Connolly and Phillips (1994)

Event-Related Potential Components Reflect Phonological and Semantic Processing of the Terminal Word of Spoken Sentences:

- The piano is out of tune (no mismatch)
- The piano is out of tuna (N400)
- The piano is out of pizza (N400 and PMN)

# Connolly and Phillips (1994)

Event-Related Potential Components Reflect Phonological and Semantic Processing of the Terminal Word of Spoken Sentences:

- The piano is out of tune (no mismatch)
- The piano is out of tuna (N400)
- The piano is out of pizza (N400 and PMN)
- ...

Introduction

oooooooooooooooooooo●oooo

Methods

oooooooooooo

Experiment 1

oooooooooooooooooooo

Experiment 2

oooooooooooooooooooo

General Discussion

oooooooooooo

Newman et al. (2003)

Phoneme deletion task to study the PMN:

# Newman et al. (2003)

Phoneme deletion task to study the PMN:

Delete /k/ from the word “clap”



# Newman et al. (2003)

Phoneme deletion task to study the PMN:

Delete /k/ from the word “clap”

- lap

# Newman et al. (2003)

Phoneme deletion task to study the PMN:

Delete /k/ from the word “clap”

- lap
- aap

# Newman et al. (2003)

Phoneme deletion task to study the PMN:

Delete /k/ from the word “clap”

- lap
- aap
- dog

# Phonological Mapping Negativity

Lewendon et. al (2020) suggest that the possibility exists that the PMN is an extension of either the Mismatch Negativity (MMN) or N400 components

# Phonological Mapping Negativity

Lewendon et. al (2020) also report that the majority of the literature on the PMN is characterized by contradictory findings and methodological limitations, e.g.

- Contrasting theories of the PMN

# Phonological Mapping Negativity

Lewendon et. al (2020) also report that the majority of the literature on the PMN is characterized by contradictory findings and methodological limitations, e.g.

- Contrasting theories of the PMN
- Mixed topographical locations:

# Phonological Mapping Negativity

Lewendon et. al (2020) also report that the majority of the literature on the PMN is characterized by contradictory findings and methodological limitations, e.g.

- Contrasting theories of the PMN
- Mixed topographical locations:
  - Some studies report discovering the PMN in frontal and central sites, others in parietal / mid-line / evenly spread across the scalp.

# Phonological Mapping Negativity

Lewendon et. al (2020) also report that the majority of the literature on the PMN is characterized by contradictory findings and methodological limitations, e.g.

- Contrasting theories of the PMN
- Mixed topographical locations:
  - Some studies report discovering the PMN in frontal and central sites, others in parietal / mid-line / evenly spread across the scalp.
- Methodological limitations:



# Phonological Mapping Negativity

Lewendon et. al (2020) also report that the majority of the literature on the PMN is characterized by contradictory findings and methodological limitations, e.g.

- Contrasting theories of the PMN
- Mixed topographical locations:
  - Some studies report discovering the PMN in frontal and central sites, others in parietal / mid-line / evenly spread across the scalp.
- Methodological limitations:
  - Few participants (usually  $< 10$ )

# Phonological Mapping Negativity

Lewendon et. al (2020) also report that the majority of the literature on the PMN is characterized by contradictory findings and methodological limitations, e.g.

- Contrasting theories of the PMN
- Mixed topographical locations:
  - Some studies report discovering the PMN in frontal and central sites, others in parietal / mid-line / evenly spread across the scalp.
- Methodological limitations:
  - Few participants (usually  $< 10$ )
  - Few trials (usually  $< 40$ )

# Phonological Mapping Negativity

Lewendon et. al (2020) also report that the majority of the literature on the PMN is characterized by contradictory findings and methodological limitations, e.g.

- Contrasting theories of the PMN
- Mixed topographical locations:
  - Some studies report discovering the PMN in frontal and central sites, others in parietal / mid-line / evenly spread across the scalp.
- Methodological limitations:
  - Few participants (usually  $< 10$ )
  - Few trials (usually  $< 40$ )
  - Confounding variables

Introduction

oooooooooooooooooooo●o

Methods

oooooooooo

Experiment 1

oooooooooooooooooo

Experiment 2

oooooooooooooo

General Discussion

oooooooooo

# Research questions

# Research questions

- **Is the PMN in response to acoustic, phonetic, phonological, lexical mapping and mismatch, none or a combination of all?**

# Research questions

- Is the PMN in response to acoustic, phonetic, phonological, lexical mapping and mismatch, none or a combination of all?
- Is any other ERP component found in response to acoustic, phonetic and phonological mismatch in place of / together with the PMN?

Introduction

oooooooooooooooooooo●

Methods

oooooooooo

Experiment 1

oooooooooooooooo

Experiment 2

oooooooooooooo

General Discussion

oooooooooo

# Research questions

Why the PMN..

Introduction

oooooooooooooooooooo●

Methods

oooooooo

Experiment 1

oooooooooooooooo

Experiment 2

oooooooooooo

General Discussion

oooooooo

# Research questions

Why the PMN.. and why now?



# Research questions

Why the PMN.. and why now?

- The PMN (placed in between phonetic and lexical processing) might play a key role in future investigations into architectures of grammar and speech perception

# Research questions

## Why the PMN.. and why now?

- The PMN (placed in between phonetic and lexical processing) might play a key role in future investigations into architectures of grammar and speech perception
- Clinical studies have recently used the PMN as a marker of phonological processing abilities in patient populations (Robson et al. 2017). However, it is not clear what processes the PMN really indexes.

Introduction

oooooooooooooooooooo

Methods

●oooooooo

Experiment 1

oooooooooooooooo

Experiment 2

oooooooooooo

General Discussion

oooooooo

Section 2

Methods

Introduction

oooooooooooooooooooo

Methods

o●oooooooo

Experiment 1

oooooooooooooooo

Experiment 2

oooooooooooo

General Discussion

oooooooo

# Experimental design

# Experimental design

Three neuro-imaging experiments designed to introduce new contexts in which to probe the elicitation of the PMN component.

# Experimental design

Three neuro-imaging experiments designed to introduce new contexts in which to probe the elicitation of the PMN component.

Experiments **1**, **2** (and **3**) were designed to simultaneously work independently while also being fully comparable.

Introduction

oooooooooooooooooooo

Methods

oo●ooooo

Experiment 1

oooooooooooooooo

Experiment 2

oooooooooooo

General Discussion

oooooooo

# Equipment & Processing

Hardware:

# Equipment & Processing

## Hardware:

- 64 active pin-type **BioSemi** electrodes for the scalp



# Equipment & Processing

## Hardware:

- 64 active pin-type **BioSemi** electrodes for the scalp
- 6 (EX1 to EX6) face electrodes

# Equipment & Processing

## Hardware:

- 64 active pin-type **BioSemi** electrodes for the scalp
- 6 (EX1 to EX6) face electrodes
- BioSemi hardware (e.g. receiver)

Introduction

oooooooooooooooooooo

Methods

ooo●oooo

Experiment 1

oooooooooooooooo

Experiment 2

oooooooooooo

General Discussion

oooooooo

# Equipment & Processing

Software:

# Equipment & Processing

## Software:

- Praat (w/ Vocal Toolkit)

# Equipment & Processing

## Software:

- Praat (w/ Vocal Toolkit)
- BioSemi Actiview

# Equipment & Processing

## Software:

- Praat (w/ Vocal Toolkit)
- BioSemi Actiview
- Neurobehavioral Systems' **Presentation**

# Equipment & Processing

## Software:

- Praat (w/ Vocal Toolkit)
- BioSemi Actiview
- Neurobehavioral Systems' **Presentation**
- MATLAB (2018b; 2019a; 2019b)

# Equipment & Processing

## Software:

- Praat (w/ Vocal Toolkit)
- BioSemi Actiview
- Neurobehavioral Systems' **Presentation**
- MATLAB (2018b; 2019a; 2019b)
- EEGLAB (Delorme & Makeig 2004)



# Equipment & Processing

## Software:

- Praat (w/ Vocal Toolkit)
- BioSemi Actiview
- Neurobehavioral Systems' **Presentation**
- MATLAB (2018b; 2019a; 2019b)
- EEGLAB (Delorme & Makeig 2004)
- ERPLAB (Lopez-Calderon & Luck, 2014)

# Equipment & Processing

## Software:

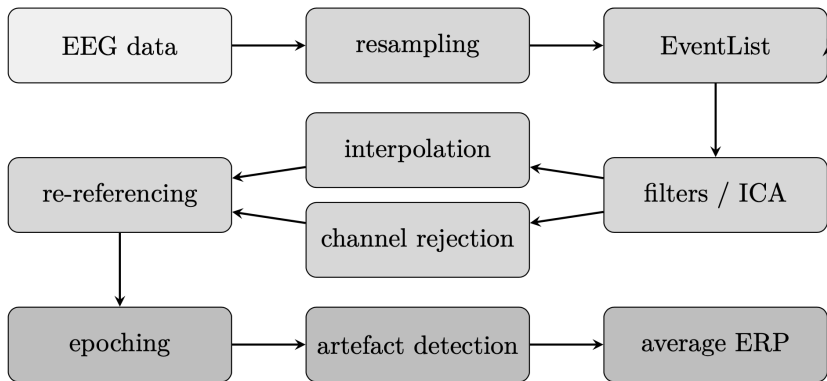
- Praat (w/ Vocal Toolkit)
- BioSemi Actiview
- Neurobehavioral Systems' **Presentation**
- MATLAB (2018b; 2019a; 2019b)
- EEGLAB (Delorme & Makeig 2004)
- ERPLAB (Lopez-Calderon & Luck, 2014)
- R (4.1) (R Core Team 2021)

# Equipment & Processing

EEG pre-processing:

# Equipment & Processing

EEG pre-processing:



Introduction

oooooooooooooooooooo

Methods

oooo●ooo

Experiment 1

oooooooooooooooo

Experiment 2

oooooooooooo

General Discussion

oooooooo

# Equipment & Processing

EEG pre-processing:

# Equipment & Processing

EEG pre-processing:

- Offline average reference

# Equipment & Processing

EEG pre-processing:

- Offline average reference
- 512 Hz sampling frequency

# Equipment & Processing

EEG pre-processing:

- Offline average reference
- 512 Hz sampling frequency
- 0.01 - 40 Hz band-pass filter



# Equipment & Processing

EEG pre-processing:

- Offline average reference
- 512 Hz sampling frequency
- 0.01 - 40 Hz band-pass filter
- 50 Hz notch filter for AC hum

Introduction

oooooooooooooooooooo

Methods

oooooo●oo

Experiment 1

oooooooooooooooo

Experiment 2

oooooooooooo

General Discussion

oooooooo

# Equipment & Processing

Statistical analyses:

# Equipment & Processing

Statistical analyses:

- Exploratory channel-level multivariate testing with package **ERP** (Causeur et al. 2020) and the Adaptive Factor Adjustment (AFA) procedure (Sheu et al. 2016)

# Equipment & Processing

Statistical analyses:

- Exploratory channel-level multivariate testing with package **ERP** (Causeur et al. 2020) and the Adaptive Factor Adjustment (AFA) procedure (Sheu et al. 2016)
- Mean amplitude modelling with mixed-effect models & package **lme4** (Bates et al. 2015)

Introduction

oooooooooooooooooooo

Methods

oooooooo●o

Experiment 1

oooooooooooooooo

Experiment 2

oooooooooooo

General Discussion

oooooooo

# Equipment

Data visualisation:

# Equipment

Data visualisation:

- Grand-Average / difference ERP plots with `ggplot2` (Wickham 2016)

# Equipment

Data visualisation:

- Grand-Average / difference ERP plots with `ggplot2` (Wickham 2016)
- Cubic spline interpolation scalp maps with package `akima` (Akima and Gebhardt 2020)

Introduction

oooooooooooooooooooo

Methods

oooooooo●

Experiment 1

oooooooooooooooo

Experiment 2

oooooooooooo

General Discussion

oooooooo

# Reproducibility





Introduction

oooooooooooooooooooo

Methods

oooooooo●

Experiment 1

oooooooooooooooo

Experiment 2

oooooooooooo

General Discussion

oooooooo

# Reproducibility



Slides for this talk are available on GitHub at the following repository:  
`mcanzi/2021_UNIKON`

Introduction

oooooooooooooooooooo

Methods

oooooooo●

Experiment 1

oooooooooooooooooooo

Experiment 2

oooooooooooooooooooo

General Discussion

oooooooooooo

# Reproducibility



Slides for this talk are available on GitHub at the following repository:  
`mcanzi/2021_UNIKON`

# Reproducibility



Slides for this talk are available on GitHub at the following repository:

`mcanzi/2021_UNIKON`

Data, code and model summaries are available on GitHub at the following repository

`mcanzi/phd_codedata`

# Reproducibility



Slides for this talk are available on GitHub at the following repository:

`mcanzi/2021_UNIKON`

Data, code and model summaries are available on GitHub at the following repository

`mcanzi/phd_codedata`

My thesis has been submitted and will be available through open access following thesis defense (in August) and corrections.

## Section 3

### Experiment 1

# Procedure

- Participants were trained to learn three pairs of tri-syllabic nonce words, presented auditorily, in a computerized training phase (e.g. pitabu dipida)

# Procedure

- Participants were trained to learn three pairs of tri-syllabic nonce words, presented auditorily, in a computerized training phase (e.g. pitabu dipida)
  - Transitional probabilities within the two items of each nonce-word pair was 1.0

# Procedure

- Participants were trained to learn three pairs of tri-syllabic nonce words, presented auditorily, in a computerized training phase (e.g. pitabu dipida)
  - Transitional probabilities within the two items of each nonce-word pair was 1.0
- Participants were tested on their knowledge of the experimental stimuli in a computerized task



# Procedure

- Participants were trained to learn three pairs of tri-syllabic nonce words, presented auditorily, in a computerized training phase (e.g. pitabu dipida)
  - Transitional probabilities within the two items of each nonce-word pair was 1.0
- Participants were tested on their knowledge of the experimental stimuli in a computerized task
- During EEG data collection, stimuli were played to participants during a passive listening task, however..

# Procedure

- Participants were trained to learn three pairs of tri-syllabic nonce words, presented auditorily, in a computerized training phase (e.g. pitabu dipida)
  - Transitional probabilities within the two items of each nonce-word pair was 1.0
- Participants were tested on their knowledge of the experimental stimuli in a computerized task
- During EEG data collection, stimuli were played to participants during a passive listening task, however..
  - In 33% of total trials (400 total trials), the first syllable of the second nonce-word of each pair would be manipulated to break expectations

# Procedure

Before training, EEG data was recorded with subjects listening passively to the presentation of matching and mismatching nonce-word pairs. This was done in order to establish a baseline.

Introduction  
oooooooooooooooooooo

Methods  
oooooooo

Experiment 1  
ooo●oooooooooooo

Experiment 2  
oooooooooooo

General Discussion  
oooooooo

Stimuli

pitabu

Introduction  
oooooooooooooooooooo

Methods  
oooooooo

Experiment 1  
ooo●oooooooooooo

Experiment 2  
oooooooooooo

General Discussion  
oooooooo

Stimuli

pitabu dipida

# Stimuli

pitabu dipida

pitabu

# Stimuli

pitabu dipida

pitabu **b**apida

# Stimuli

pitabu dipida

pitabu **b**apida

pitabu



# Stimuli

pitabu dipida

pitabu **b**apida

pitabu **b**upida

# Stimuli

pitabu dipida

pitabu **b**apida

pitabu **b**upida

Introduction  
oooooooooooooooooooo

Methods  
oooooooo

Experiment 1  
oooo●oooooooo

Experiment 2  
oooooooooooo

General Discussion  
oooooooo

# Stimuli

- Stimuli were synthesized using Mac OS Text-to-Speech

# Stimuli

- Stimuli were synthesized using Mac OS Text-to-Speech
- Stimuli concept from Astheimer and Sanders (2011), who controlled for transitional probabilities, resemblance to real words, etc.

# Stimuli

- Stimuli were synthesized using Mac OS Text-to-Speech
- Stimuli concept from Astheimer and Sanders (2011), who controlled for transitional probabilities, resemblance to real words, etc.
- Vowel, syllable and word length were controlled (each syllable was 200 ms long)

# Stimuli

- Stimuli were synthesized using Mac OS Text-to-Speech
- Stimuli concept from Astheimer and Sanders (2011), who controlled for transitional probabilities, resemblance to real words, etc.
- Vowel, syllable and word length were controlled (each syllable was 200 ms long)
- Speaker and pitch contours were the same for all stimuli.

# Participants

22 Participants ( $F = 13$ ) took part to the experiment.

# Participants

22 Participants ( $F = 13$ ) took part to the experiment.

- 22 right-handed adults



# Participants

22 Participants ( $F = 13$ ) took part to the experiment.

- 22 right-handed adults
- 22 BrE speakers

# Participants

22 Participants ( $F = 13$ ) took part to the experiment.

- 22 right-handed adults
- 22 BrE speakers
- Age ( $M = 20$ , 18-25)

# Participants

22 Participants ( $F = 13$ ) took part to the experiment.

- 22 right-handed adults
- 22 BrE speakers
- Age ( $M = 20$ , 18-25)
- Normal or corrected to normal vision and hearing

# Participants

22 Participants ( $F = 13$ ) took part to the experiment.

- 22 right-handed adults
- 22 BrE speakers
- Age ( $M = 20$ , 18-25)
- Normal or corrected to normal vision and hearing
- No reported use of psychoactive medications

Introduction

oooooooooooooooooooo

Methods

oooooooooo

Experiment 1

ooooooo●oooooooo

Experiment 2

oooooooooooooo

General Discussion

oooooooooo

Results: **Baseline**

# Results: **Baseline**

No effects of interest were found

# Results: **Baseline**

No effects of interest were found

- Few trials

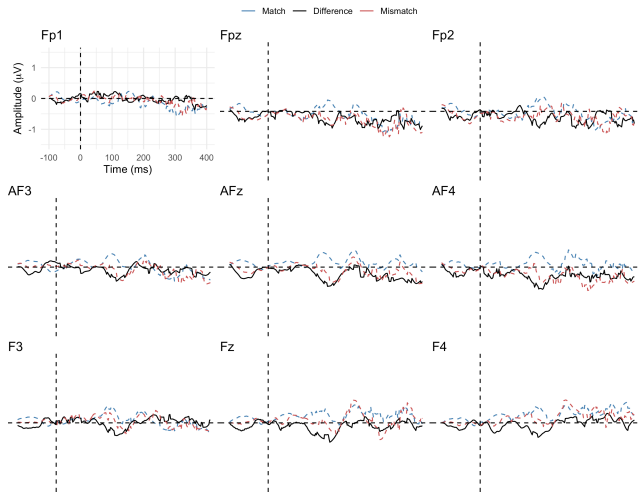
# Results: **Baseline**

No effects of interest were found

- Few trials
- Low SNR



# Results



Introduction

oooooooooooooooooooo

Methods

oooooooooo

Experiment 1

oooooooo●ooooo

Experiment 2

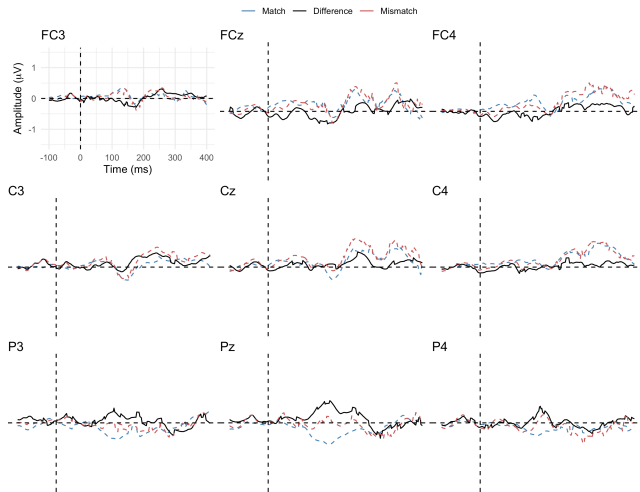
oooooooooooo

General Discussion

oooooooo

# Results

# Results

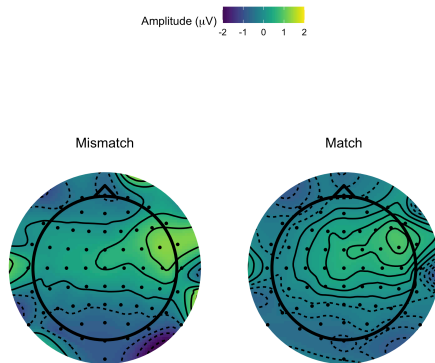


# Results: PMN

Cubic-spline interpolation scalp maps. Mean amplitude between 280 and 320 ms post-stimulus onset.

# Results: PMN

Cubic-spline interpolation scalp maps. Mean amplitude between 280 and 320 ms post-stimulus onset.



Introduction

oooooooooooooooooooo

Methods

oooooooooo

Experiment 1

oooooooooooo●ooo

Experiment 2

oooooooooooooo

General Discussion

oooooooooo

Results: **PMN**

# Results: **PMN**

We fitted a LMEM to mean amplitude measured between 280 and 320 ms PSO.

# Results: **PMN**

We fitted a LMEM to mean amplitude measured between 280 and 320 ms PSO.  
**Condition**, **Region** and **Hemisphere** were fitted as main effects as well as three-way interaction.



# Results: PMN

We fitted a LMEM to mean amplitude measured between 280 and 320 ms PSO. **Condition**, **Region** and **Hemisphere** were fitted as main effects as well as three-way interaction. Varying intercepts allowed for **Subject**

- No main effect of **Condition** [ $F_{(1,1797)} = 0.01$ ,  $p = .89$ )]

# Results: PMN

We fitted a LMEM to mean amplitude measured between 280 and 320 ms PSO. **Condition**, **Region** and **Hemisphere** were fitted as main effects as well as three-way interaction. Varying intercepts allowed for **Subject**

- No main effect of **Condition** [ $F_{(1,1797)} = 0.01$ ,  $p = .89$ )]
- No interaction of **Condition** & **Region** [ $F_{(10,1797)} = 1.39$ ,  $p = .17$ )]

## Results: Other effects

- Small negative effect between 150-200 ms for mismatch condition (frontocentral) (**MMN?**)

# Results: Other effects

- Small negative effect between 150-200 ms for mismatch condition (frontocentral) (**MMN?**)
- Bigger positive effect between 500-700 ms for mismatch condition (centroparietal) (**P600?**)

# Results: Other effects

- Small negative effect between 150-200 ms for mismatch condition (frontocentral) (**MMN?**)
- Bigger positive effect between 500-700 ms for mismatch condition (centroparietal) (**P600?**)
- In case of a significant interaction between Condition and Region, pairwise contrasts were carried out with package `emmeans` (Lenth et al. 2018)

# Discussion

No instance of **PMN** (in any of its expected forms) was found

Introduction

oooooooooooooooooooo

Methods

oooooooooo

Experiment 1

oooooooooooooooo●

Experiment 2

oooooooooooo

General Discussion

oooooooo

# Discussion

Possible explanations:

# Discussion

Possible explanations:

- PMN is more "higher-level" than previously theorized



# Discussion

Possible explanations:

- PMN is more "higher-level" than previously theorized
- Methodological limitations of Exp. 1

# Discussion

Possible explanations:

- PMN is more "higher-level" than previously theorized
- Methodological limitations of Exp. 1
  - Passive listening

# Discussion

Possible explanations:

- PMN is more "higher-level" than previously theorized
- Methodological limitations of Exp. 1
  - Passive listening
  - Possible P3a contamination?

## Section 4

## Experiment 2

Introduction

oooooooooooooooooooo

Methods

oooooooo

Experiment 1

oooooooooooooooo

Experiment 2

o●oooooooo

General Discussion

oooooooo

# Methods

# Methods

- Designed to be (fairly) comparable to experiment one

# Methods

- Designed to be (fairly) comparable to experiment one
  - Same stimuli as Exp 1

# Methods

- Designed to be (fairly) comparable to experiment one
  - Same stimuli as Exp 1
  - No lexical activation



# Methods

- Designed to be (fairly) comparable to experiment one
  - Same stimuli as Exp 1
  - No lexical activation
- Includes active, behavioural tasks

# Methods

- Designed to be (fairly) comparable to experiment one
  - Same stimuli as Exp 1
  - No lexical activation
- Includes active, behavioural tasks
- More streamlined

Introduction

oooooooooooooooooooo

Methods

oooooooo

Experiment 1

oooooooooooooooo

Experiment 2

oo●oooooooo

General Discussion

oooooooo

Stimuli

Same nonce words as **Experiment 1**

# Procedure

di +

# Procedure

di + (500 ms pause) +

# Procedure

di + (500 ms pause) + pi +

# Procedure

di + (500 ms pause) + pi + (500 ms pause) +

# Procedure

di + (500 ms pause) + pi + (500 ms pause) + da



# Procedure

di + (500 ms pause) + pi + (500 ms pause) + da  
(4 s pause)

# Procedure

di + (500 ms pause) + pi + (500 ms pause) + da  
(4 s pause)  
dipida

# Procedure

However, in 33% of total trials

di

# Procedure

However, in 33% of total trials

di pi

# Procedure

However, in 33% of total trials

di pi da

# Procedure

However, in 33% of total trials

di pi da

**b**apida

# Participants

20 participants ( $F = 12$ ) took part to the experiment:

# Participants

20 participants ( $F = 12$ ) took part to the experiment:

- 20 right-handed adults



# Participants

20 participants ( $F = 12$ ) took part to the experiment:

- 20 right-handed adults
- 20 BrE speakers

# Participants

20 participants ( $F = 12$ ) took part to the experiment:

- 20 right-handed adults
- 20 BrE speakers
- Age ( $M = 19$ , 18-24)

# Participants

20 participants ( $F = 12$ ) took part to the experiment:

- 20 right-handed adults
- 20 BrE speakers
- Age ( $M = 19$ , 18-24)
- Normal or corrected to normal vision and hearing

# Participants

20 participants ( $F = 12$ ) took part to the experiment:

- 20 right-handed adults
- 20 BrE speakers
- Age ( $M = 19$ , 18-24)
- Normal or corrected to normal vision and hearing
- No reported use of psychoactive medications

# Participants

20 participants ( $F = 12$ ) took part to the experiment:

- 20 right-handed adults
- 20 BrE speakers
- Age ( $M = 19$ , 18-24)
- Normal or corrected to normal vision and hearing
- No reported use of psychoactive medications
- 0 took part to both Exp 1 and Exp 2

Introduction

oooooooooooooooooooo

Methods

oooooooooo

Experiment 1

oooooooooooooooooo

Experiment 2

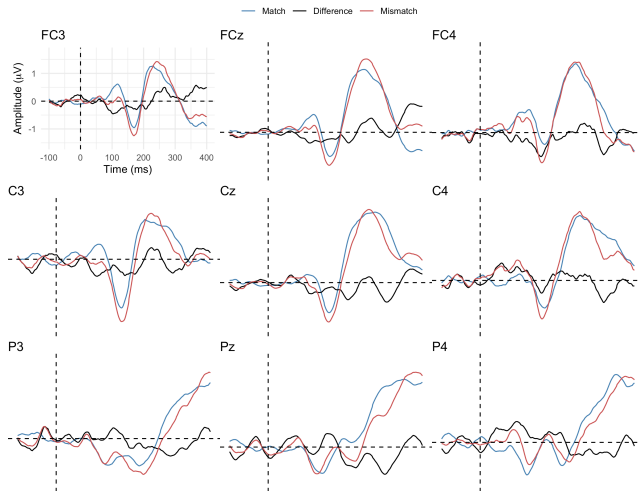
ooooooo●oooooo

General Discussion

oooooooooo

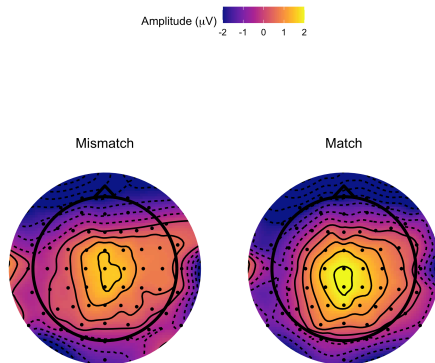
# Results

# Results



# Results: PMN

Cubic-spline interpolation scalp maps. Mean amplitude between 280 and 320 ms post-stimulus onset.





Introduction

oooooooooooooooooooo

Methods

oooooooo

Experiment 1

oooooooooooooooo

Experiment 2

oooooooo●ooo

General Discussion

oooooooo

Results: **PMN**

# Results: **PMN**

We fitted a LMEM to mean amplitude measured between 280 and 320 ms PSO.

# Results: **PMN**

We fitted a LMEM to mean amplitude measured between 280 and 320 ms PSO.

**Condition**, **Region** and **Hemisphere** were fitted as main effects as well as three-way interaction.

# Results: PMN

We fitted a LMEM to mean amplitude measured between 280 and 320 ms PSO.

**Condition**, **Region** and **Hemisphere** were fitted as main effects as well as three-way interaction. Varying intercepts allowed for **Subject**

- No main effect of **Condition** [ $F_{(1,1965.6)} = 0.0001$ ,  $p = .98$ )]

# Results: PMN

We fitted a LMEM to mean amplitude measured between 280 and 320 ms PSO.

**Condition**, **Region** and **Hemisphere** were fitted as main effects as well as three-way interaction. Varying intercepts allowed for **Subject**

- No main effect of **Condition** [ $F(1,1965.6) = 0.0001$ ,  $p = .98$ )]
- Significant interaction of **Condition** & **Region** [ $F(10,1948.2) = 0.8$ ,  $p = .001$ )].  
However..

# Results: PMN

We fitted a LMEM to mean amplitude measured between 280 and 320 ms PSO.

**Condition**, **Region** and **Hemisphere** were fitted as main effects as well as three-way interaction. Varying intercepts allowed for **Subject**

- No main effect of **Condition** [ $F_{(1,1965.6)} = 0.0001$ ,  $p = .98$ )]
- Significant interaction of **Condition** & **Region** [ $F_{(10,1948.2)} = 0.8$ ,  $p = .001$ )].  
However..
- Only significant main effect on Condition between match ( $M = 0.51 \mu V$ ) and mismatch ( $M = -0.04 \mu V$ ) at parieto-occipital scalp sites.

# Results: Other effects

- Small negative effect between 75-125 ms for mismatch condition (frontal) (**N1?**)

# Results: Other effects

- Small negative effect between 75-125 ms for mismatch condition (frontal) (**N1?**)
- Small negative effect between 150-200 ms for mismatch condition (left hemisphere) (**MMN? ELAN?**)



# Results: Other effects

- Small negative effect between 75-125 ms for mismatch condition (frontal) (**N1?**)
- Small negative effect between 150-200 ms for mismatch condition (left hemisphere) (**MMN? ELAN?**)
- Bigger positive effect between 500-700 ms for mismatch condition (centroparietal) (**P600?**)

# Discussion

No instance of **PMN** (in any of its expected forms) was found

Introduction

oooooooooooooooooooo

Methods

oooooooooo

Experiment 1

oooooooooooooooooo

Experiment 2

oooooooooooo●

General Discussion

oooooooo

# Discussion

Possible explanations:

# Discussion

Possible explanations:

- PMN is more "higher-level" than previously theorized

# Discussion

Possible explanations:

- PMN is more "higher-level" than previously theorized
- ~~Methodological limitations of Exp. 1~~

## Section 5

# General Discussion

# PMN?

Contrasting findings in PMN literature cause:

- Difficulty in determining whether an observed response matches the PMN (in function and topographical distribution)

# PMN?

Contrasting findings in PMN literature cause:

- Difficulty in determining whether an observed response matches the PMN (in function and topographical distribution)
- Easy to mistake any component in a similar range as the PMN



# PMN?

Contrasting findings in PMN literature cause:

- Difficulty in determining whether an observed response matches the PMN (in function and topographical distribution)
- Easy to mistake any component in a similar range as the PMN
- Bulk of the (very limited) literature on the PMN attributed to one research group

# PMN?

The PMN appears to be linked to lexical processing more than to the processing of pre-lexical information (including acoustic and phonetic information).

# PMN?

The PMN appears to be linked to lexical processing more than to the processing of pre-lexical information (including acoustic and phonetic information).

- This supports earlier theories of the PMN (e.g. Connolly & Phillips 1994)

# PMN?

The PMN appears to be linked to lexical processing more than to the processing of pre-lexical information (including acoustic and phonetic information).

- This supports earlier theories of the PMN (e.g. Connolly & Phillips 1994)
- Goes against later interpretations (e.g. Newman et al. 2003)

# PMN?

The PMN appears to be linked to lexical processing more than to the processing of pre-lexical information (including acoustic and phonetic information).

- This supports earlier theories of the PMN (e.g. Connolly & Phillips 1994)
- Goes against later interpretations (e.g. Newman et al. 2003)
- How much of the PMN is in response to phonological information specifically?

# PMN?

The PMN appears to be linked to lexical processing more than to the processing of pre-lexical information (including acoustic and phonetic information).

- This supports earlier theories of the PMN (e.g. Connolly & Phillips 1994)
- Goes against later interpretations (e.g. Newman et al. 2003)
- How much of the PMN is in response to phonological information specifically?
  - Issues with uses of PMN in clinical settings

# Other findings

Earlier responses (150-200 ms) and later P600-like effects reinforce:

# Other findings

Earlier responses (150-200 ms) and later P600-like effects reinforce:

- Mismatch stimuli were recognised as such

Could the PMN be a later instance of the MMN?



# Other findings

Earlier responses (150-200 ms) and later P600-like effects reinforce:

- Mismatch stimuli were recognised as such
- Early, acoustic / phonetic mismatch

Could the PMN be a later instance of the MMN?

# Other findings

Earlier responses (150-200 ms) and later P600-like effects reinforce:

- Mismatch stimuli were recognised as such
- Early, acoustic / phonetic mismatch
- P600 as an index of sequence violation

Could the PMN be a later instance of the MMN?

Introduction

oooooooooooooooooooo

Methods

oooooooooo

Experiment 1

oooooooooooooooooo

Experiment 2

oooooooooooooo

General Discussion

oooo●ooo

Future directions

# Future directions

- Explore other responses to stimulus presentation in Exp 1 and 2

# Future directions

- Explore other responses to stimulus presentation in Exp 1 and 2
- Determine whether they are to acoustic, phonetic, phonological features of stimuli..

# Future directions

- Explore other responses to stimulus presentation in Exp 1 and 2
- Determine whether they are to acoustic, phonetic, phonological features of stimuli..
  - Done in Exp 3. Data collection interrupted by COVID-19

# Future directions

- Explore other responses to stimulus presentation in Exp 1 and 2
- Determine whether they are to acoustic, phonetic, phonological features of stimuli..
  - Done in Exp 3. Data collection interrupted by COVID-19
- Try different paradigms that isolate phonological and lexical processing

# Methodological limitations

If we consider the non-observation of the PMN as a cause of methodological limitations:



# Methodological limitations

If we consider the non-observation of the PMN as a cause of methodological limitations:

- PMN most likely not reliable enough as a marker for clinical experiments

# Methodological limitations

If we consider the non-observation of the PMN as a cause of methodological limitations:

- PMN most likely not reliable enough as a marker for clinical experiments
- Not a good candidate for experiments investigating information flow order in speech perception

Introduction

oooooooooooooooooooo

Methods

oooooooo

Experiment 1

oooooooooooooooo

Experiment 2

oooooooooooo

General Discussion

oooooo●o

PMN: All the right places

Introduction

oooooooooooooooooooo

Methods

oooooooo

Experiment 1

oooooooooooooooo

Experiment 2

oooooooooooo

General Discussion

oooooo●o

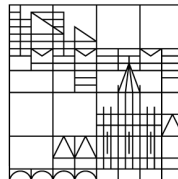
PMN: All the right places

Replication

# Thank you!

Special thanks to my supervisors **Dr Wendell Kimper** and **Dr Patrycja Strycharczuk**

Universität  
Konstanz



The University of Manchester