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

Massimiliano Canzi massimiliano.canzi@uni-konstanz.de

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Section 1

Introduction

Introduction

Four years ago...

Introduction

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

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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)

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

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

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- 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)

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- 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

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Christma/**s-**ʃ/ /**t-k**/capes

Cool, huh?

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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

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- Phonological Mapping* Negativity (**PMN**)

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- Phonological Mapping***** Negativity (**PMN**)
- **N400**
- **P600**

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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

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- 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.

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nurse

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nurse doctor | pizza pineapple

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

Phonological Mapping Negativity

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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..

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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:

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- The piano is out of

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

- The piano is out of tune (no mismatch)

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

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

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- The piano is out of pizza (N400 and PMN)

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

Newman et al. (2003)

Phoneme deletion task to study the PMN:

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Delete /k/ from the word “clap”

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- lap

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- 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

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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.

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  - Some studies report discovering the PMN in frontal and central sites, others in parietal / mid-line / evenly spread across the scalp.

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  - Few trials (usually < 40)

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  - Few participants (usually < 10)
  - Few trials (usually < 40)
  - Confounding variables

Research questions

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

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- **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?**

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Why the PMN..

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Why the PMN.. and why now?

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

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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.

Section 2

Methods

Experimental design

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

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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.

Equipment & Processing

Hardware:

Equipment & Processing

Hardware:

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

Equipment & Processing

Hardware:

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- 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)

Equipment & Processing

Software:

Equipment & Processing

Software:

- Praat (w/ Vocal Toolkit)

Equipment & Processing

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- BioSemi Actiview

Equipment & Processing

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- Neurobehavioral Systems' **Presentation**

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Equipment & Processing

Software:

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- MATLAB (2018b; 2019a; 2019b)
- EEGLAB (Delorme & Makeig 2004)
- ERPLAB (Lopez-Calderon & Luck, 2014)

Equipment & Processing

Software:

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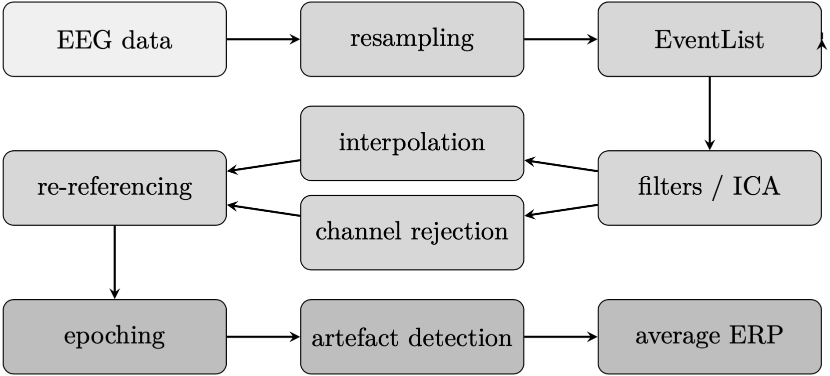
- MATLAB (2018b; 2019a; 2019b)
- EEGLAB (Delorme & Makeig 2004)
- ERPLAB (Lopez-Calderon & Luck, 2014)
- R (4.1) (R Core Team 2021)

Equipment & Processing

EEG pre-processing:

Equipment & Processing

EEG pre-processing:



Equipment & Processing

EEG pre-processing:

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EEG pre-processing:

- Offline average reference

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- 512 Hz sampling frequency

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EEG pre-processing:

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- 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

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)

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- 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)

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)

Reproducibility

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Data, code and model summaries are available on GitHub at the repository `mcanzi/phd_codedata`

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Data, code and model summaries are available on GitHub at the repository `mcanzi/phd_codedata`

PhD 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)

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- During EEG data collection, stimuli were played to participants during a passive listening task, however..

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- 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 estabilish a baseline.

Stimuli

pitabu

Stimuli

pitabu dipida

Stimuli

pitabu dipida

pitabu

Stimuli

pitabu dipida

pitabu **ba**pida

Stimuli

pitabu dipida

pitabu **ba**pida

pitabu

Stimuli

pitabu dipida

pitabu **ba**pida

pitabu **bu**pida

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Stimuli

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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.

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- 22 right-handed adults

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- 22 right-handed adults
- 22 BrE speakers

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- Age (M = 20, 18-25)

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Participants

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- 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

Results: **Baseline**

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No effects of interest were found

Results: **Baseline**

No effects of interest were found

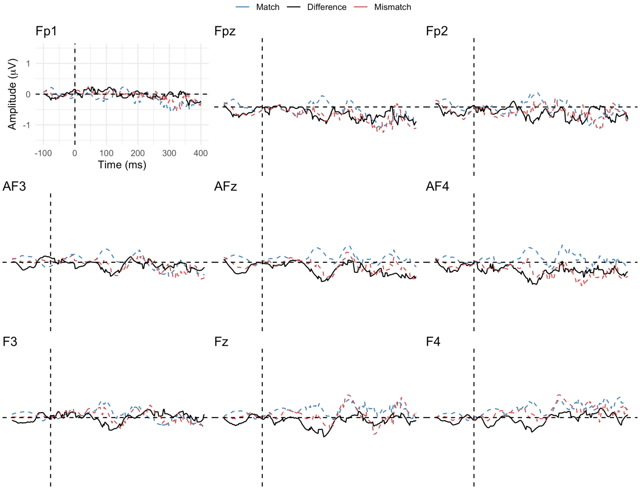
- Few trials

Results: **Baseline**

No effects of interest were found

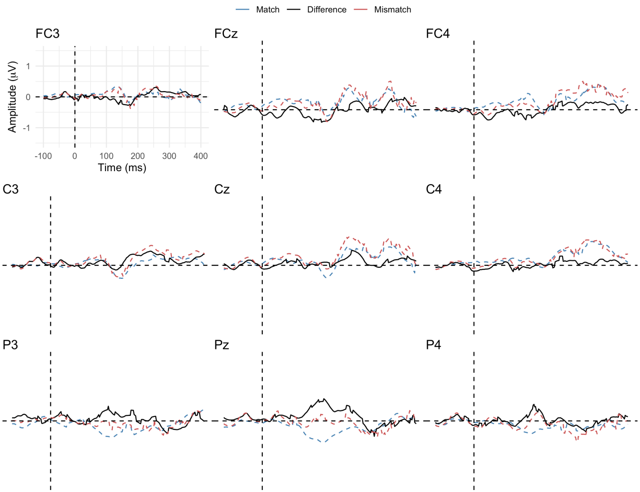
- Few trials
- Low SNR

Results


Match
Difference
Mismatch
Fp1
Fpz
Fp2
AF3
AFz
AF4
F3
Fz
F4
Amplitude (μV)
1
0
-1
-100
0
100
200
300
400
Time (ms)

Results

Results


Match
Difference
Mismatch
FC3
FCz
FC4
C3
Cz
C4
P3
Pz
P4
Amplitude (µV)
1
0
-1
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400
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Results: **PMN**

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

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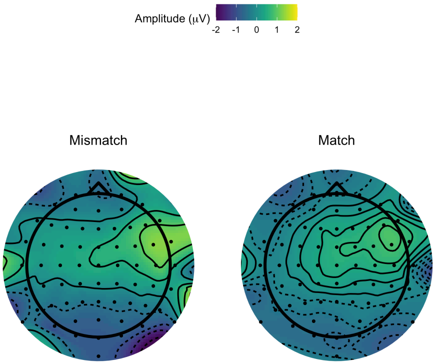

Results: **PMN**

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

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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

Discussion

Possible explanations:

Discussion

Possible explanations:

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

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

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

Methods

Methods

- Designed to be (fairly) comparable to experiment one

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    - Same stimuli as Exp 1

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  - 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

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

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di pi da

bapida

Participants

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

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- 20 right-handed adults

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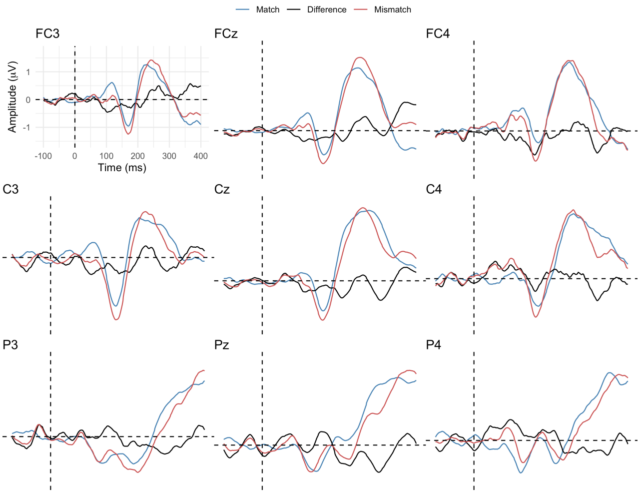
- 20 BrE speakers
- Age (M = 19, 18-24)
- Normal or corrected to normal vision and hearing
- No reported use of psychoactive medications
- 0 took part to both Exp 1 and Exp 2

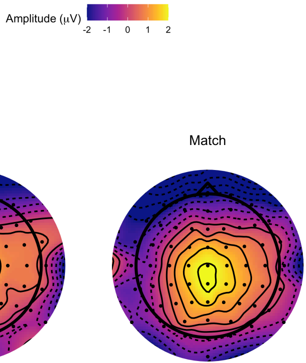
Results

Results


Match
Difference
Mismatch
FC3
FCz
FC4
C3
Cz
C4
P3
Pz
P4
Amplitude (µV)
1
0
-1
-100
0
100
200
300
400
Time (ms)

Results: **PMN**

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



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- 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?**)

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

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- 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

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Possible explanations:

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- ~~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)

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- 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

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

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- 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:

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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?

Future directions

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

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- Determine whether they are to acoustic, phonetic, phonological features of stimuli..

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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:

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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

PMN: **All the right places**

PMN: **All the right places**

Replication

Thank you!

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

Universität Konstanz

MANCHESTER 1824
The University of Manchester