

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

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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.

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Top-down vs bottom-up in speech perception:

Introduction

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- 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)

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- 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.

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- Magnuson et al. (2003). Lexical effects on compensation for coarticulation: **The ghost of Christmash past**. *Cognitive Science*, 27(2), 285-298.

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

Ganong effect (Ganong 1980)

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- e.g. Christma/s-ʃ/ more often solved as Christma/s/.

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- 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-ʃ/ /t-k/capes

Cool, huh?

Introduction

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Event-related potentials

ERP (and EEG) offer unparalleled temporal resolution,

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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.

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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**)

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Event-related potentials

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

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Event-related potentials

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

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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

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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)

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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

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

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- MMN to the presentation of mismatching Finnish words

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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.

N400

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nurse

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nurse doctor

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nurse doctor | pizza

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nurse doctor | pizza pineapple

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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

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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

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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:

Connolly and Phillips (1994)

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- 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:

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

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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)
- The piano is out of tuna (N400)
- The piano is out of pizza

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

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

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- ...

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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

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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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- Methodological limitations:

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 - Few trials (usually < 40)

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- 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

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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?

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Research questions

Why the PMN..

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Research questions

Why the PMN.. and why now?

Research questions

Why the PMN.. and why now?

- The PMN might play an important role in future investigations of architectures of grammar (placed in between acoustic and lexical processing)

Research questions

Why the PMN.. and why now?

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

Section 2

Methods

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Experimental design

Experimental design

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

Experimental design

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

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

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Equipment & Processing

Hardware:

Equipment & Processing

Hardware:

- 64 active pin-type **BioSemi** electrodes

Equipment & Processing

Hardware:

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

Equipment & Processing

Hardware:

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

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Equipment & Processing

Software:

Equipment & Processing

Software:

- BioSemi Actiview

Equipment & Processing

Software:

- BioSemi Actview
- Neurobehavioral Systems' **Presentation**

Equipment & Processing

Software:

- BioSemi Actview
- Neurobehavioral Systems' **Presentation**
- MATLAB (2018b; 2019a; 2019b)

Equipment & Processing

Software:

- BioSemi ActiView
- Neurobehavioral Systems' **Presentation**
- MATLAB (2018b; 2019a; 2019b)
- EEGLAB (Delorme & Makeig 2004)

Equipment & Processing

Software:

- BioSemi ActiView
- Neurobehavioral Systems' **Presentation**
- MATLAB (2018b; 2019a; 2019b)
- EEGLAB (Delorme & Makeig 2004)
- ERPLAB (Lopez-Calderon & Luck, 2014)

Equipment & Processing

Software:

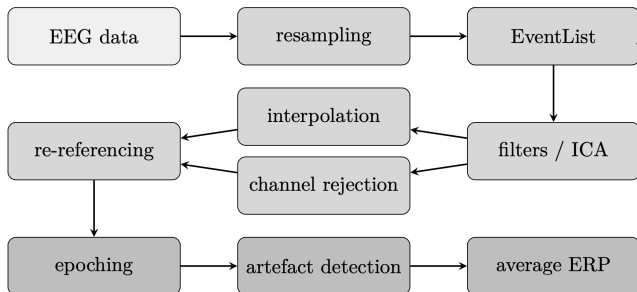
- BioSemi ActiView
- Neurobehavioral Systems' **Presentation**
- MATLAB (2018b; 2019a; 2019b)
- EEGLAB (Delorme & Makeig 2004)
- ERPLAB (Lopez-Calderon & Luck, 2014)
- R (4.1) (R Core Team 2021)

Equipment & Processing

EEG pre-processing:

Equipment & Processing

EEG pre-processing:



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

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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)

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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)

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Reproducibility



Reproducibility



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

Reproducibility



Data, code and model summaries are freely 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 in a computerized training phase (e.g. pitabu dipida)

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 - Transitional probabilities within the two items of each nonce-word pair was 1.0

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

Procedure

- Participants were trained to learn three pairs of tri-syllabic nonce words 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 back 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

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Stimuli

pitabu

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

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

Stimuli

pitabu dipida

pitabu **b**apida

pitabu **b**upida

- Stimuli were synthesized using Mac OS Text-to-Speech
- Vowel, syllable and word length were controlled (each syllable was 200 ms long)

Stimuli

pitabu dipida

pitabu **b**apida

pitabu **b**upida

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

Participants

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- 22 right-handed adults
- 22 BrE speakers

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

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- 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

Results: PMN

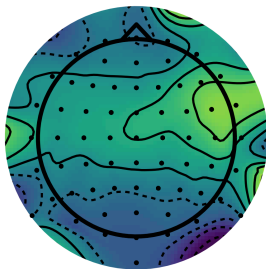
Cubic-spline interpolation scalp maps. Mean amplitude between 280 and 320 ms post-stimulus onset.

Results: PMN

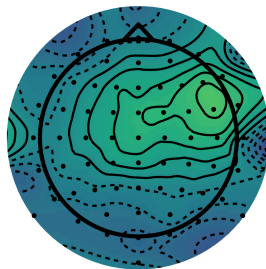
Cubic-spline interpolation scalp maps. Mean amplitude between 280 and 320 ms post-stimulus onset.



Mismatch



Match



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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. Varying intercepts allowed for **Subject**

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

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

Results: Other effects

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

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- 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

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Methods

oooooooooooo

Experiment 1

ooooooooo●

Experiment 2

oooooooooooo

General Discussion

ooooooo

Discussion

Possible explanations:

Discussion

Possible explanations:

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

Discussion

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

Discussion

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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

Introduction

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Methods

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Experiment 1

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Experiment 2

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General Discussion

ooooooo

Methods

Methods

- Designed to be (fairly) comparable to experiment one

Methods

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 - 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

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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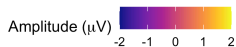
Participants

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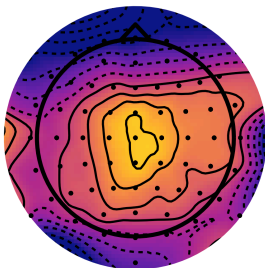
- 20 right-handed adults
- 20 BrE speakers
- Age ($M = 19$, 18-24)
- Normal or corrected to normal vision and hearing
- No reported use of psychoactive medications

Results: PMN

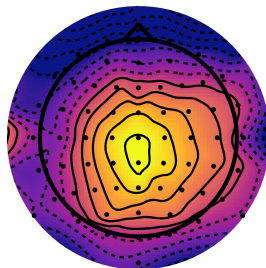
Cubic-spline interpolation scalp maps. Mean amplitude between 280 and 320 ms post-stimulus onset.



Mismatch



Match



Introduction

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Methods

oooooooooooo

Experiment 1

oooooooooooo

Experiment 2

oooooooo●ooo

General Discussion

ooooooo

Results: **PMN**

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

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- 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?**)

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

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

Discussion

Possible explanations:

Discussion

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Possible explanations:

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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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- 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?

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- 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
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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?

Methodological limitations

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

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- 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

Thank you!

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