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Quantitative Linguistics
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Analyzing EEG data using GAMs

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Fr, June 28, 2013 • LOT school 2013

Subject pronouns

Example: *Yesterday, James talked to Rob.*

He admitted the theft.

➜Pronouns (*he*, *him*) do not have a fixed meaning

- Interpretation is influenced by many factors, such as:
  - linguistic principles (Binding Theory, Chomsky, 1981) - object pronouns!
  - discourse prominence (e.g., Ariel, 1990; Arnold, 1998)
  - perspective taking (Gundel et al., 1993)

Processing of subject pronouns

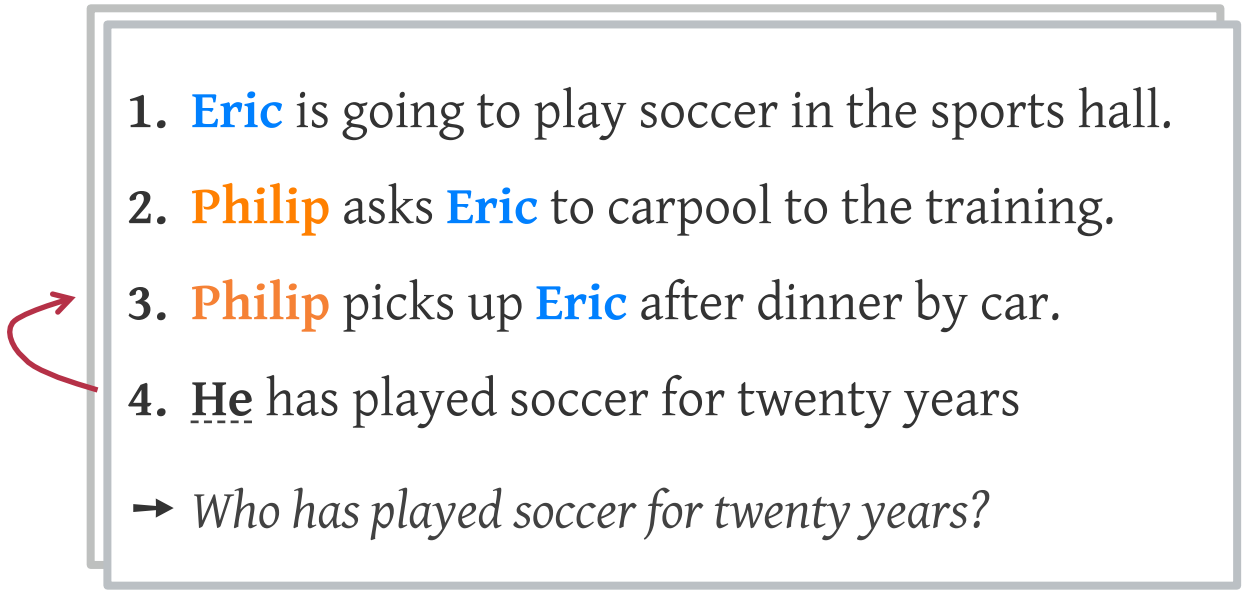
- Subject pronouns refer to the discourse topic
  - **discourse topic** = most salient referent in context

- The previous subject is a very likely discourse topic for adults (a.o., Arnold, 1998; Grosz et al., 1995)

Adults' processing of subject pronouns

- Subject pronouns refer to the subject of previous sentence

Example:



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Acquisition of subject pronouns

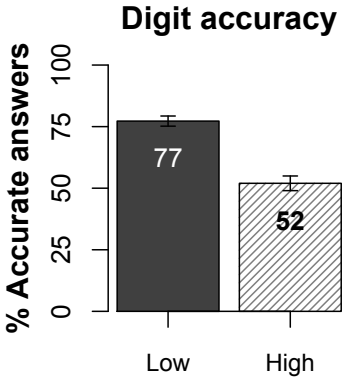
1. **Eric** is going to play so
2. **Philip** asks **Eric** to carp
3. **Philip** picks up **Eric** afte
4. **He** has played soccer for t

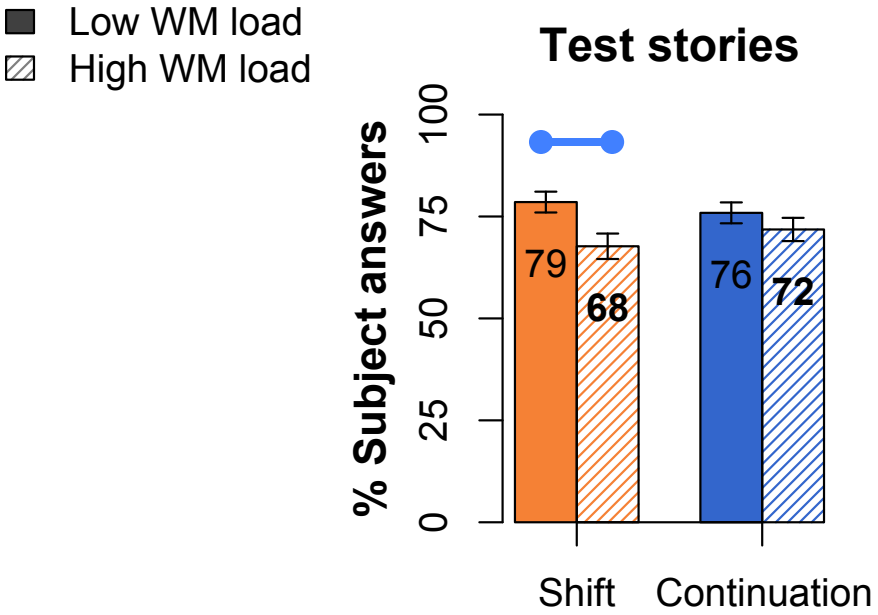
→ *Who has played soccer for tw*

- The previous subject is a very likely discourse topic for adults (a.o., Arnold, 1998; Grosz et al., 1995)
- However, children do not seem to use grammatical role
  - Correlation with WM capacity (Koster et al., 2011)
- Question: can low WM capacity cause children's in adult-like performance on pronoun processing?

Dual-task study (off-line)

- WM load manipulation: memorize 3 or 6 digits
- Comprehension questions:





➜Subject is **less often** selected as referent of the pronoun;

➜most frequent referent is **more often** selected

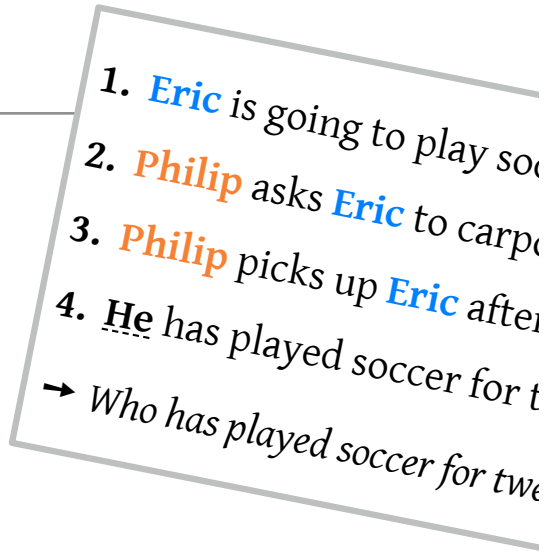
(Van Rij, van Rijn, & Hendriks, *TopiCS*, 2013)

Question

- Prediction: Using information about grammatical role requires sufficient WM capacity

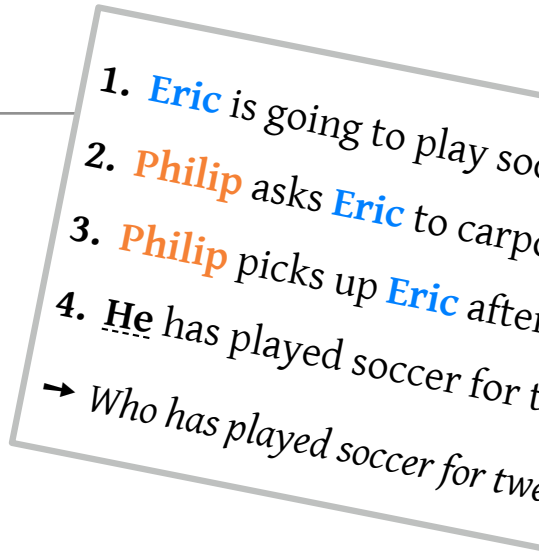
➔ to keep referents that are relevant for the story (the previous subject) in an activated state

  - Question: Does **on-line pronoun processing** reflect that with high WM load the accessibility of the previous subject decreases?



Dual-task EEG study

When is discourse ambiguity resolved?

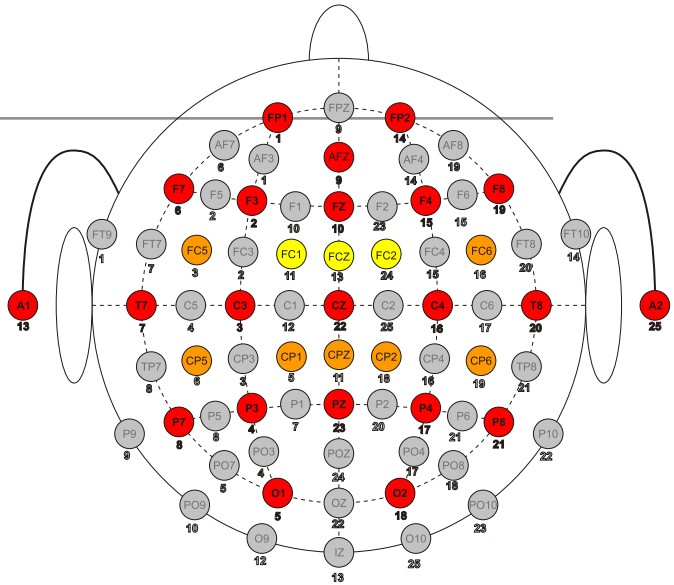


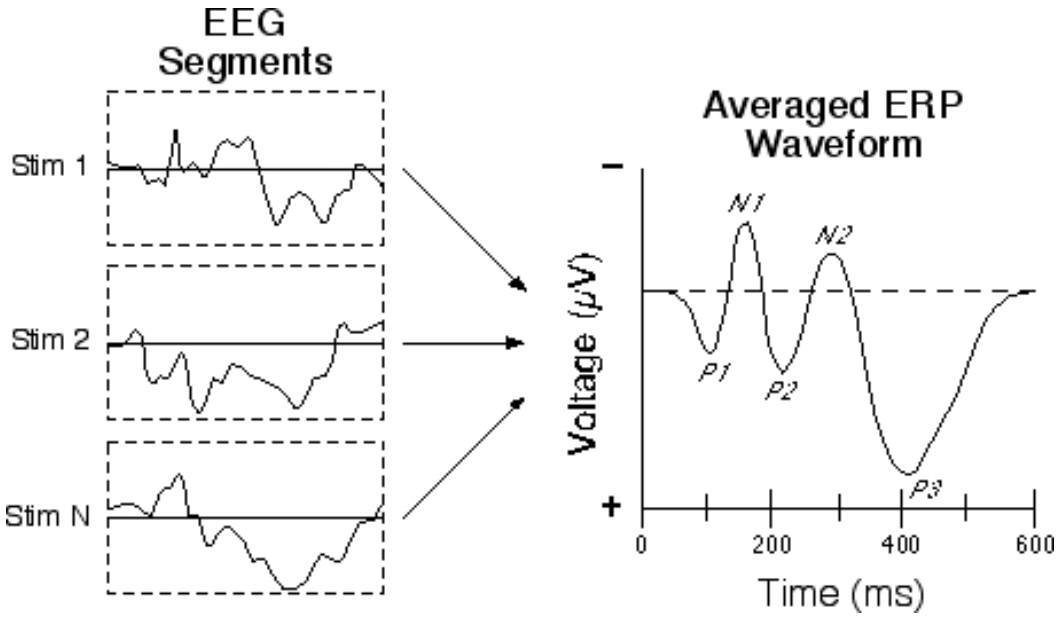
Task

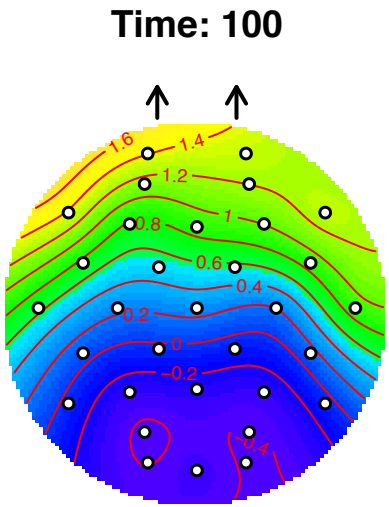
- Dual-task experiment
  - Memory task: 3 or 6 digits (low vs high WM load)
  - Reading task, followed by comprehension questions:
    - Short stories with a topic shift or topic continuation
    - Variable serial visual presentation procedure (Nieuwland & van Berkum, 2006)
- 21 participants
- 160 test items, each 2 variants (topic shift - topic continuation)
  - 64 followed by test questions, 96 by filler question
  - EEG: 40 items per condition per subject

ERP data

- Today: analysis of single electrode recording
  - GAMs allow for spatial distribution analyses



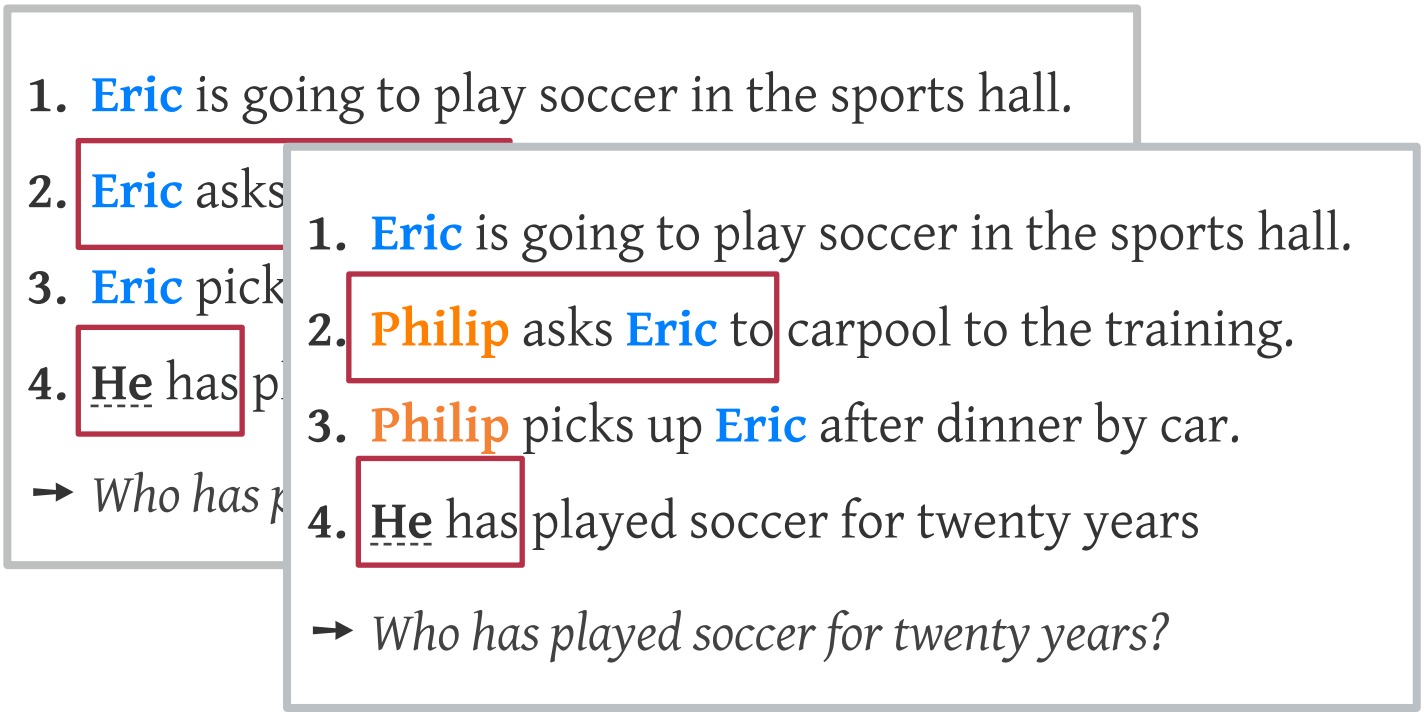




(picture from https://uwaterloo.ca/event-related-potential-lab)

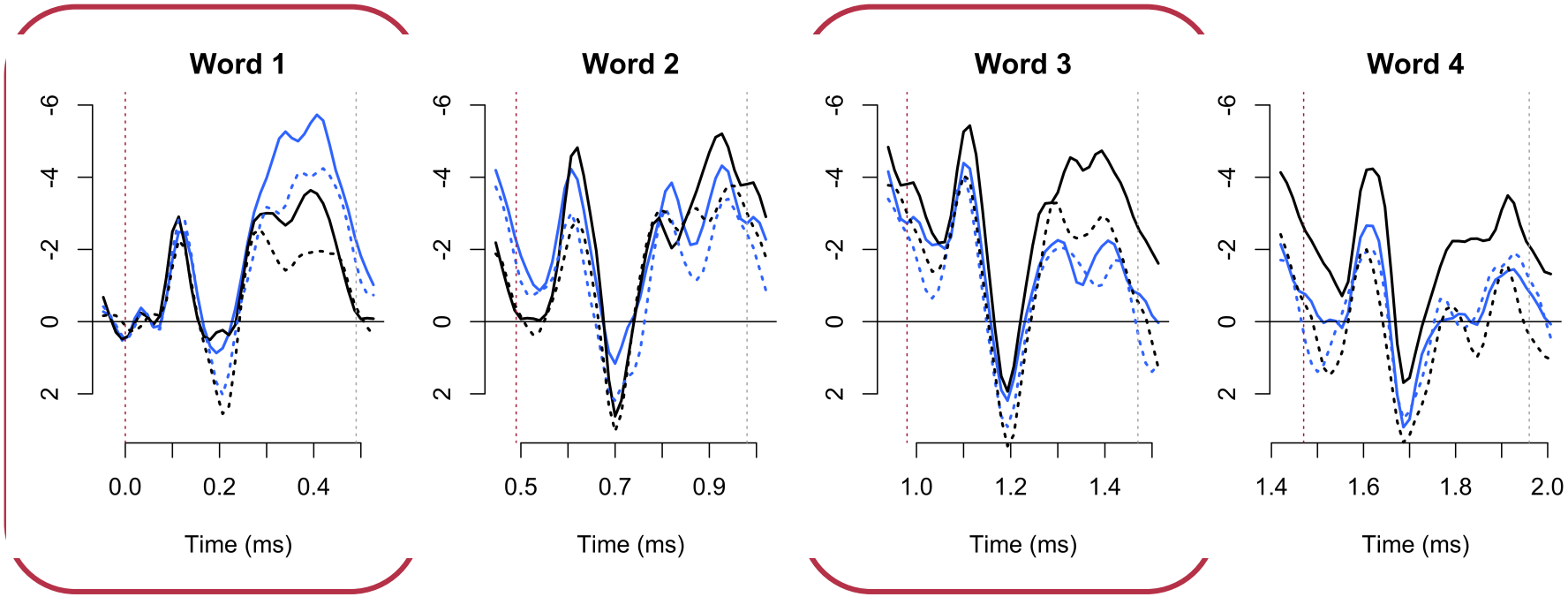
ERP data

- Two analysis regions:



EEG signal Sentence 2

Eric	asks	**Philip**	to...
Philip	asks	**Eric**	to...



Analysis

- Separate GAM analysis for each region (580 ms)
  - Example: Word 1 Sentence 1

- Incorrect memory task trials excluded
  - all digits correct for low WM load condition (22% excl)
  - max 1 digit incorrect for high WM load condition (19.1% excl)

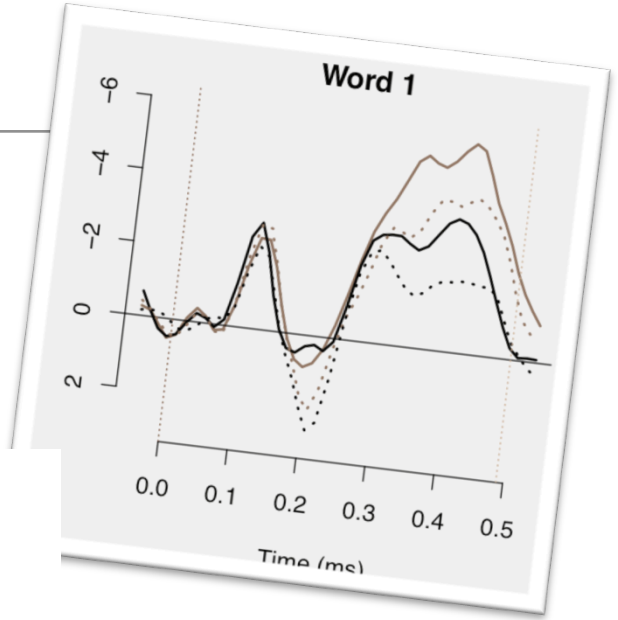
- Important binary predictors: *Shift* (1=topic shift), *WM load* (1=high WM load), *Interaction* (Shift x WM load, 1= topic shift - high WM)
- Other predictors: *Trial* (centered), *handedness*

Data

```
> head(dat1)
  Subject Item       Time Trial   Trial.c Shift WM Interaction
1    s020 i100 -0.5000000    10 -66.10692     0  0           0
2    s020 i100 -0.4866667    10 -66.10692     0  0           0
3    s020 i100 -0.4733333    10 -66.10692     0  0           0
4    s020 i100 -0.4600000    10 -66.10692     0  0           0
5    s020 i100 -0.4466667    10 -66.10692     0  0           0
6    s020 i100 -0.4333333    10 -66.10692     0  0           0

  allConditions hand gender electrode      EEG
1       -TS.low    l      v        Cz 23.52356
2       -TS.low    l      v        Cz 29.09026
3       -TS.low    l      v        Cz 24.58340
4       -TS.low    l      v        Cz 19.15406
5       -TS.low    l      v        Cz 16.72305
6       -TS.low    l      v        Cz 20.09972
```

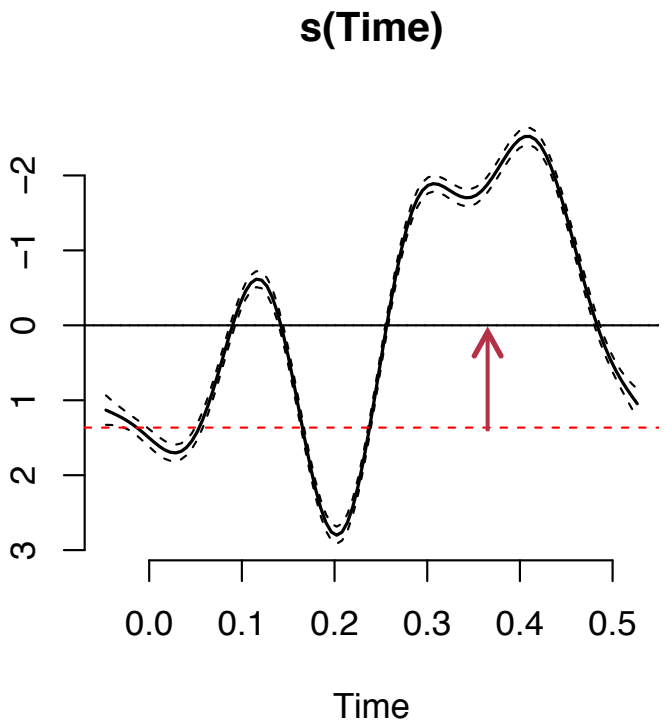
Determine baseline model

```
> summary( m0 <- bam(EEG ~ s(Time), data=dat1) )

  Parametric coefficients:
              Estimate Std. Error t value Pr(>|t|)
  (Intercept) -1.36482    0.03918  -34.83   <2e-16 ***
  ---

  Approximate significance of smooth terms:
             edf Ref.df     F p-value
  s(Time) 8.906  8.997 178.2  <2e-16 ***
  ---

  R-sq.(adj) =  0.0157   Deviance explained = 1.58%
  fREML score = 3.954e+05  Scale est. = 154.08    n = 100408
```

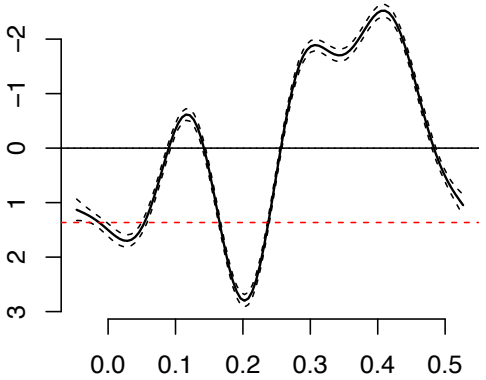


Determine baseline model

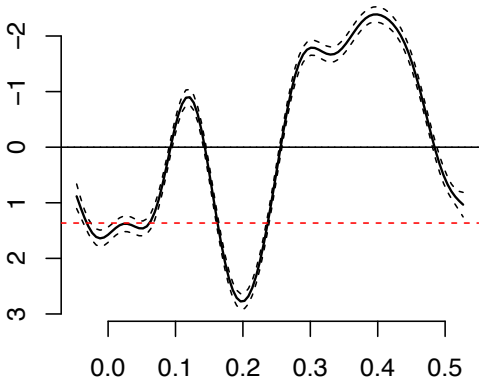
- Main effect of Time:



Check knots




```
> m0 <- bam(EEG ~ s(Time), data=dat1)
# default for s(): k=9

> m1 <- bam(EEG ~ s(Time, k=15), data=dat1)
...
s(Time) 13.16  13.87 116.7  <2e-16 ***
```




```
> anova(m0, m1, test='F')
Model 1: EEG ~ s(Time)
Model 2: EEG ~ s(Time, k = 15)
  Resid. Df Resid. Dev     Df Deviance      F    Pr(>F)
1    100398   15469005
2    100394   15465530 4.2577   3475.5 5.2989 0.0002019 ***
```

Repeated measures

- Current model does not account of random variability due to items and participants
  - Items are balanced
  - Considerable differences between subjects:
    - Informal inspection of subject differences:

```
> mc <- bam(Pupil ~ s(Time, by=Subject, k=15), data=dat1)
   ...
   Approximate significance of smooth terms:
                             edf Ref.df      F  p-value
   s(Time):Subjects020   10.205 11.880  7.893 9.77e-15 ***
   s(Time):Subjects021    7.543  9.056  5.955 2.13e-08 ***
   s(Time):Subjects022    9.953 11.640 12.059  < 2e-16 ***
   s(Time):Subjects023    7.719  9.259 13.603  < 2e-16 ***
```

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Different types of random effects with GAMs

1. Random intercept: `s(Item, bs="re")`
2. Random intercept + random slope: `s(Item, pTime, bs="re")`
3. Random wiggly curve: `s(pTime, Subject, bs="fs", m=1)`

Important notes:

- Random effects may change the fit of the fixed effects
- Random effects cause non-nested models, therefore F-test is less reliable
  - use AIC comparison instead

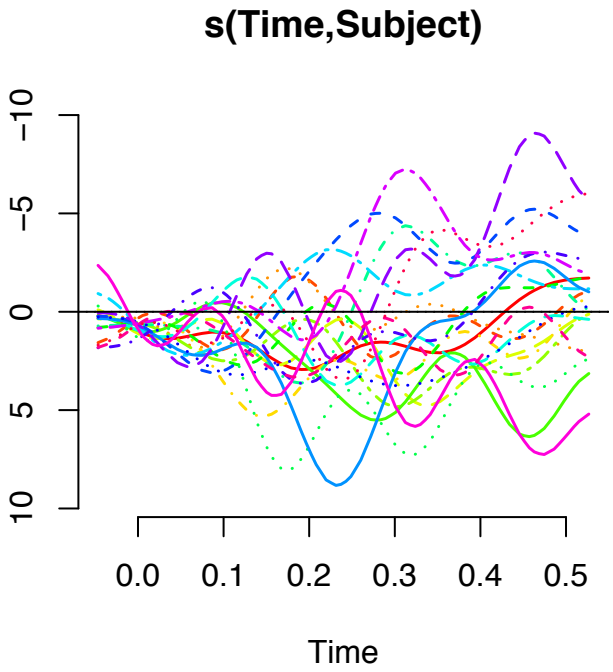
Random wiggly curves

```
> summary( m2 <- bam(EEG ~ s(Time, k=15)
        + s(Time, Subject, bs="fs", m=1), data=dat1) )

   Parametric coefficients:
               Estimate Std. Error t value Pr(>|t|)
   (Intercept)  -2.1310     0.4403   -4.84  1.3e-06 ***
   ---

   Approximate significan                 ms:
                        edf Ref.df      F p-value
   s(Time)            12.82   13.5  12.06  <2e-16 ***
   s(Time,Subject) 163.10  186.0 22.13  <2e-16 ***
   ---

   R-sq.(adj) =  0.0547   Deviance explained = 5.63%
   fREML score = 3.9366e+05  Scale est. = 147.98    n = 100408
```

before: **-1.36**

Random wiggly curves

```
> m1 <- bam(EEG ~ s(Time, k=15), data=dat1)
> m2 <- bam(EEG ~ s(Time, k=15) + s(Time, Subject, bs="fs", m=1),
        data=dat1)

# use AIC instead of anova():
> AIC(m1) - AIC(m2)
[1] 3871.741
```



AIC

- AIC (Akaike's information criterion) quantifies relative quality of a model
  - the trade-off between the complexity and the goodness of fit
  - only for comparing models: absolute value doesn't tell anything
  - model with the minimum AIC value is preferred

- The evidence ratio tells how much more likely the model's description of the data is: `exp( ( AIC(r0) - AIC(r1) ) / 2 )`
  - a difference of 2 ➜ more than 2.5x higher likelihood
  - a difference of 3 ➜ more than 4x higher likelihood

Some remarks

- Random effects structure in GAMs is less elaborate than in LMEs
  - It's not possible to include random wiggly curves for subjects and items
    ➜ too much freedom for the model
  - Psycholinguistic data: preference for random wiggly curves for subjects

- In mgcv 1.7-24 there is a problem with plotting random wiggly curves for models were also an intercept is included. This is hopefully resolved in a new version...
  - in lab session we will use custom made function

Check fixed effects

```
> m4 <- bam(EEG ~ s(Time, k=15) + s(Time, by=Shift)
        + s(Time, Subject, bs="fs", m=1) + s(Item, bs="re"),
        data=dat1)
> AIC(m3)-AIC(m4)
[1] 236.3614
> m5 <- bam(EEG ~ s(Time, k=15) + s(Time, by=Shift)
        + s(Time, by=WM) + s(Time, Subject, bs="fs", m=1)
        + s(Item, bs="re"), data=dat1)
> AIC(m4)-AIC(m5)
[1] 125.3935
> m6 <- bam(EEG ~ s(Time,k=15)   + s(Time, by=Shift)
        + s(Time, by=WM) + s(Time, by=Interaction)
        + s( Time, Subject,bs="fs", m=1) + s(Item, bs="re"),
        data=dat1)
> AIC(m5)-AIC(m6)
[1] -2.421736
```

Contrasts

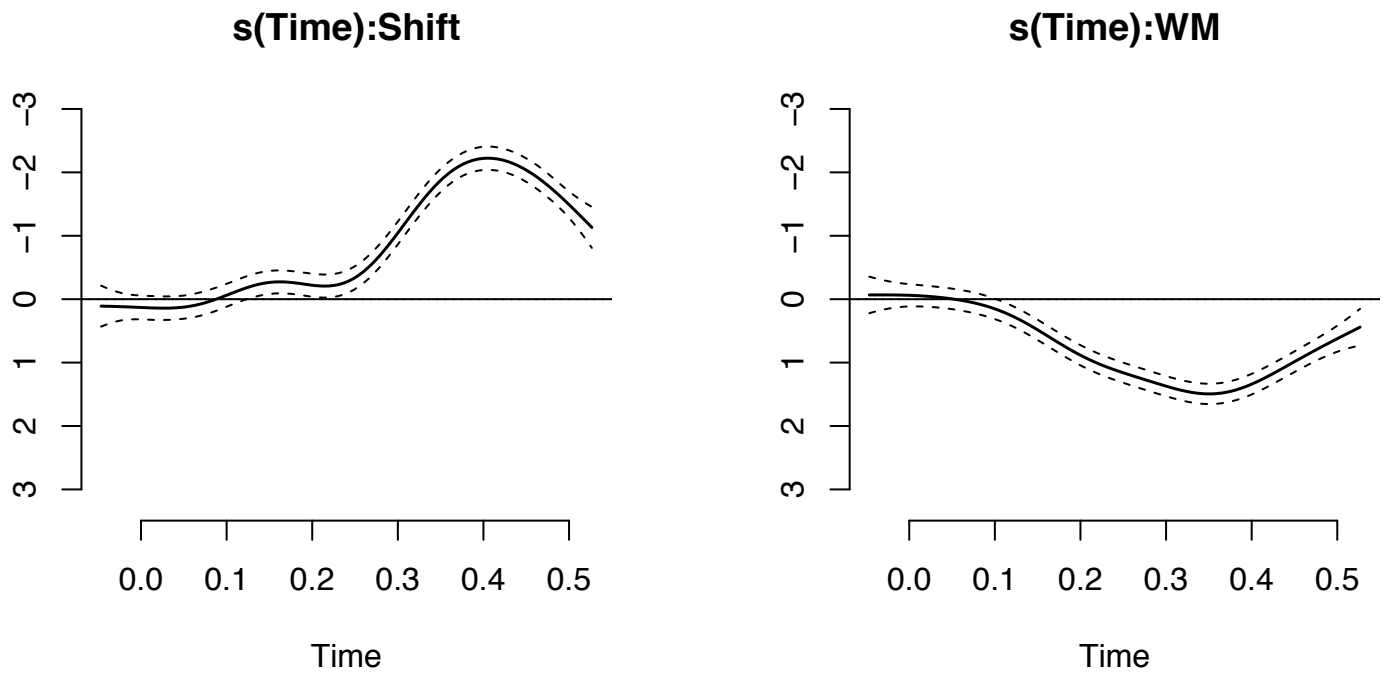
```
summary( 5 <- bam(EEG ~ s(Time, k=15) + s(Time, by=Shift)
        + s(Time, by=WM) + s(Time, Subject, bs="fs", m=1)
        + s(Item, bs="re"), data=dat1) )
```

```
...
Approximate significance of smooth terms:
                      edf  Ref.df     F p-value
s(Time)            12.786  13.475 11.28  <2e-16 ***
s(Time):Shift       6.670   7.813 31.04  <2e-16 ***
s(Time):WM          5.111   6.065 21.76  <2e-16 ***
s(Time,Subject) 163.663 186.000 26.25  <2e-16 ***
s(Item)         14[illegible]2 159.000 13.63  <2e-16 ***
```

binary predictors (0 or 1),
therefore only 1 smooth term

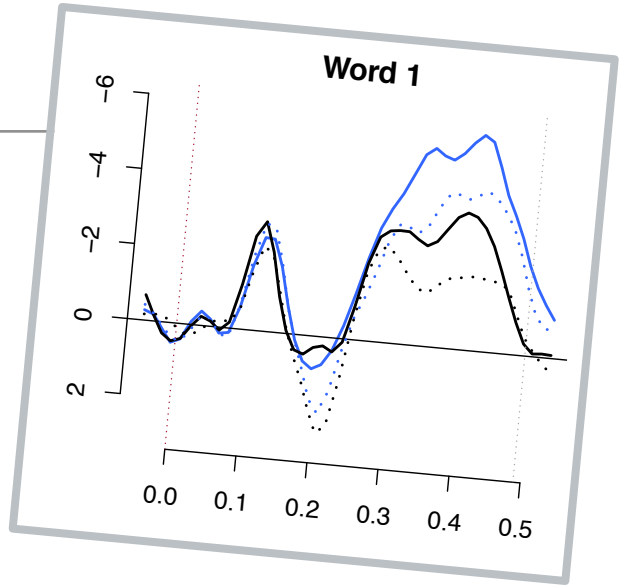
Contrasts

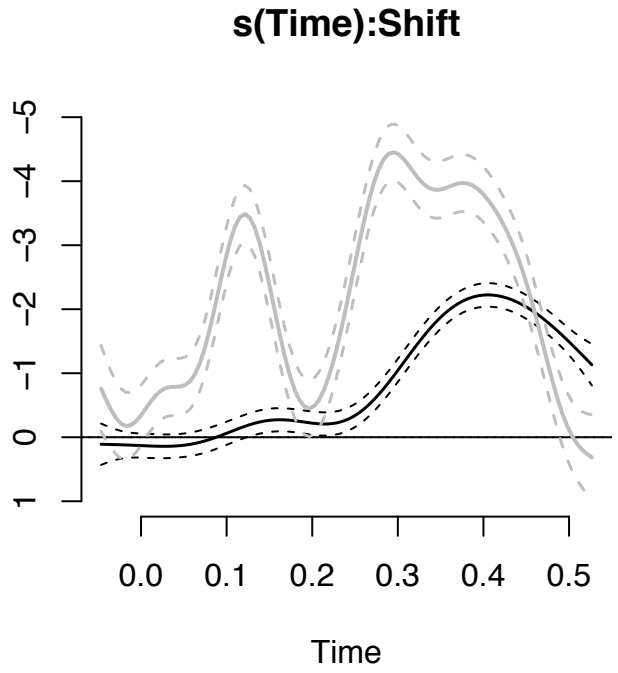
- Effects of topic shift and WM load (binary predictors)



Contrasts

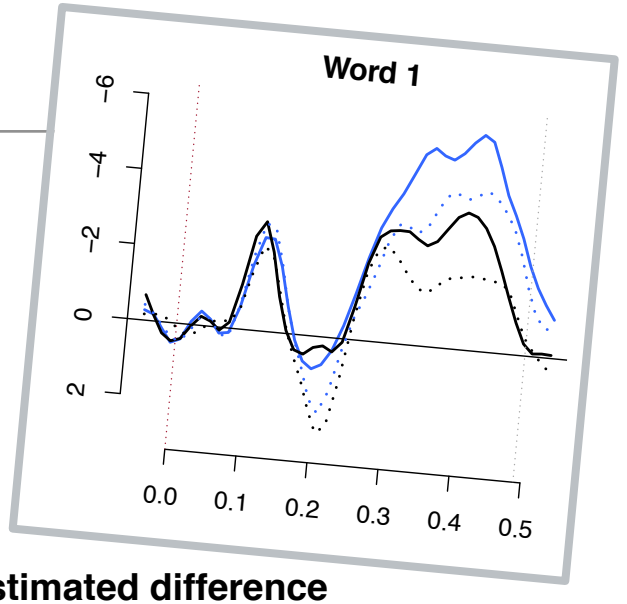
- Effects of topic shift

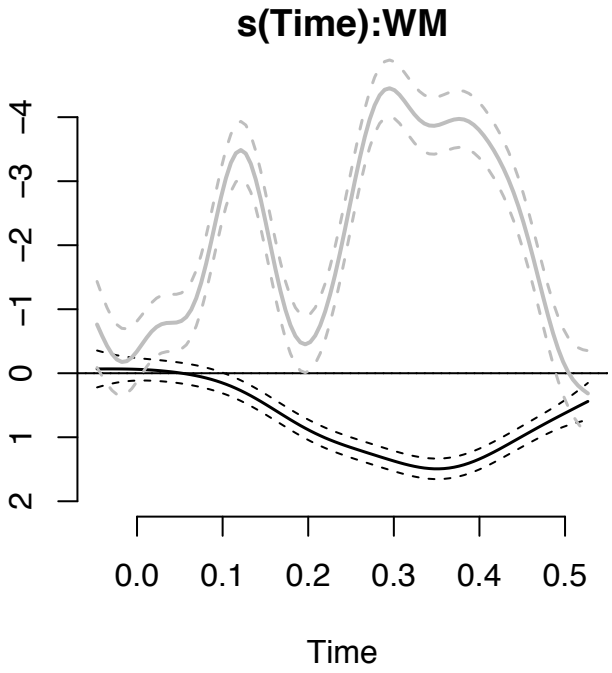


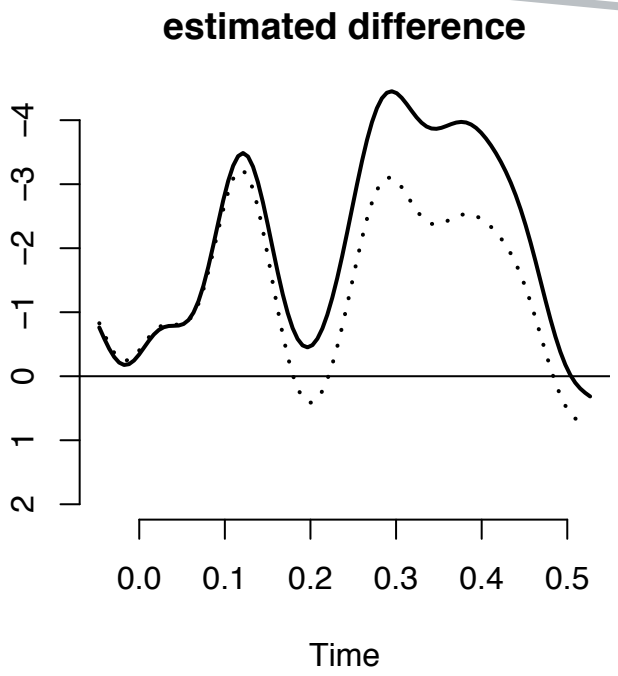


Contrasts

- Effects of WM load

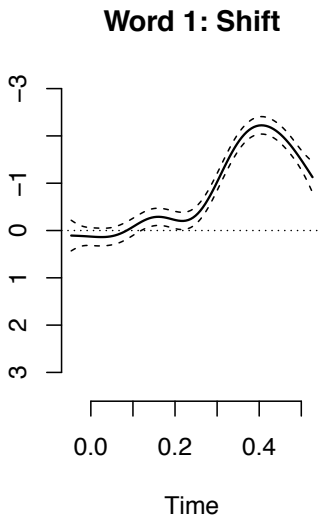


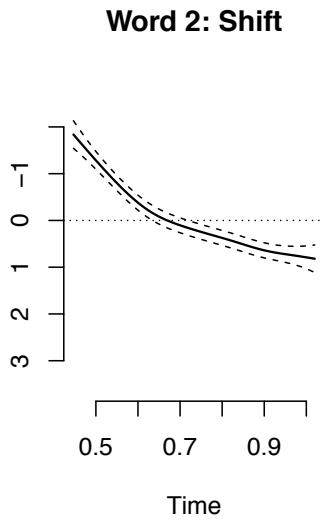


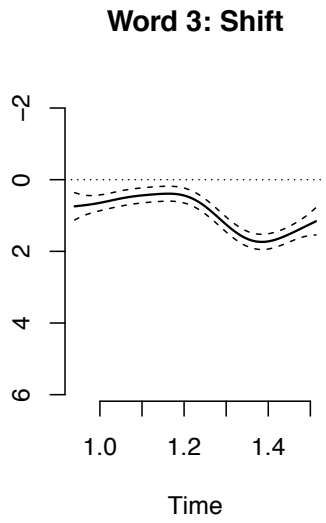


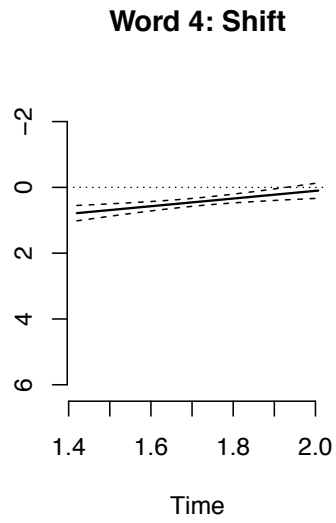
Effect of Topic shift Sentence 2

Eric	asks	**Philip**	to...
Philip	asks	**Eric**	to...



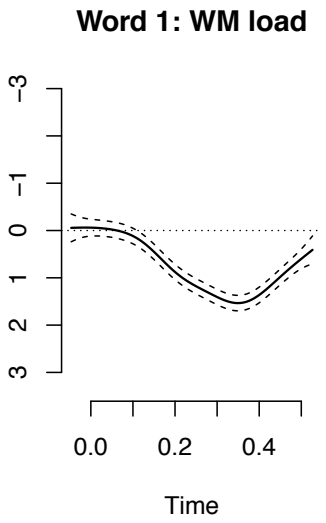


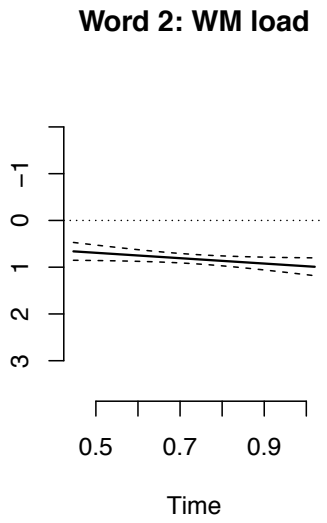


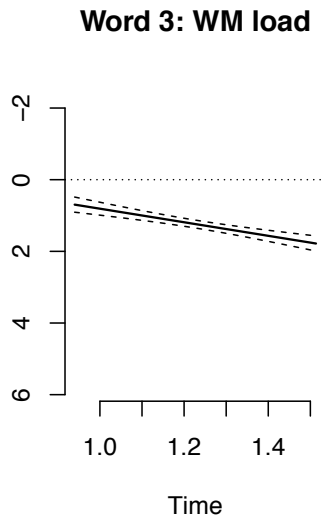


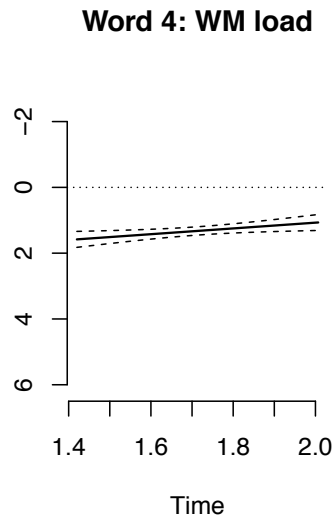
Effect of WM load Sentence 2

Eric	asks	**Philip**	to...
Philip	asks	**Eric**	to...





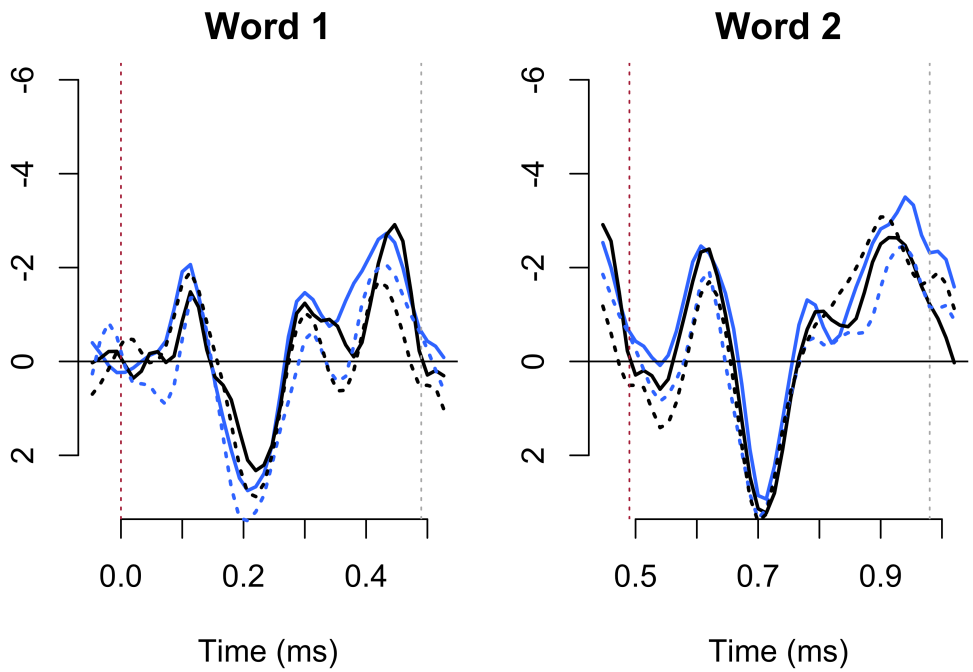




Same analysis for Sentence 4

He has...

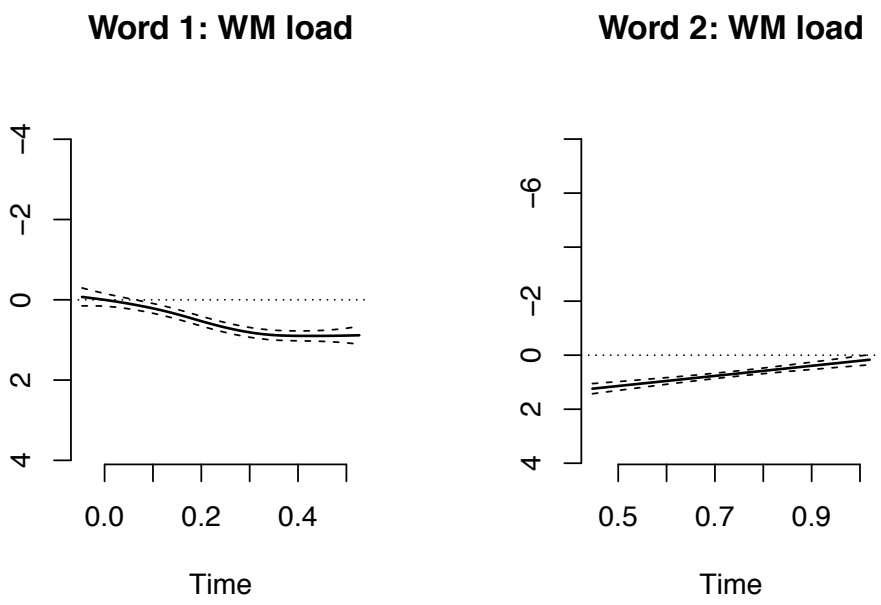
He has...



Effect of WM load

He has...

He has...



Conclusion

- Question: Does **on-line pronoun processing** reflect that with high WM load the accessibility of the previous subject decreases?
  - Yes, people seem to show a more shallow discourse processing with higher WM load (lower negativities around 400 ms) during referent processing
    - → Sufficient WM capacity is required for discourse processing
  - However, we did not find an interaction between Topic shift and WM load during on-line processing and no effect of Topic shift on the pronoun
    - → These stories may be ambiguous *off-line*, but they are not during pronoun

However...

... I did not check the residuals! (model criticism)

- Higher uncertainties, but similar effects, when correcting for auto correlation
- Tomorrow more about that topic with pupil dilation data.