Towards a causal role of Broca's area in language: a TMS-EEG study on syntactic prediction

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Introduction

Increased negativities are observed in the EEG signal (e.g., Early Syntactic Negativity – ESN [1]) for **categorical violations** (e.g., "*the eats") compared to well-formed structures (e.g., "the food"). The earliness of these effects has been attributed to the presence of syntactic **categorical predictions** [2].
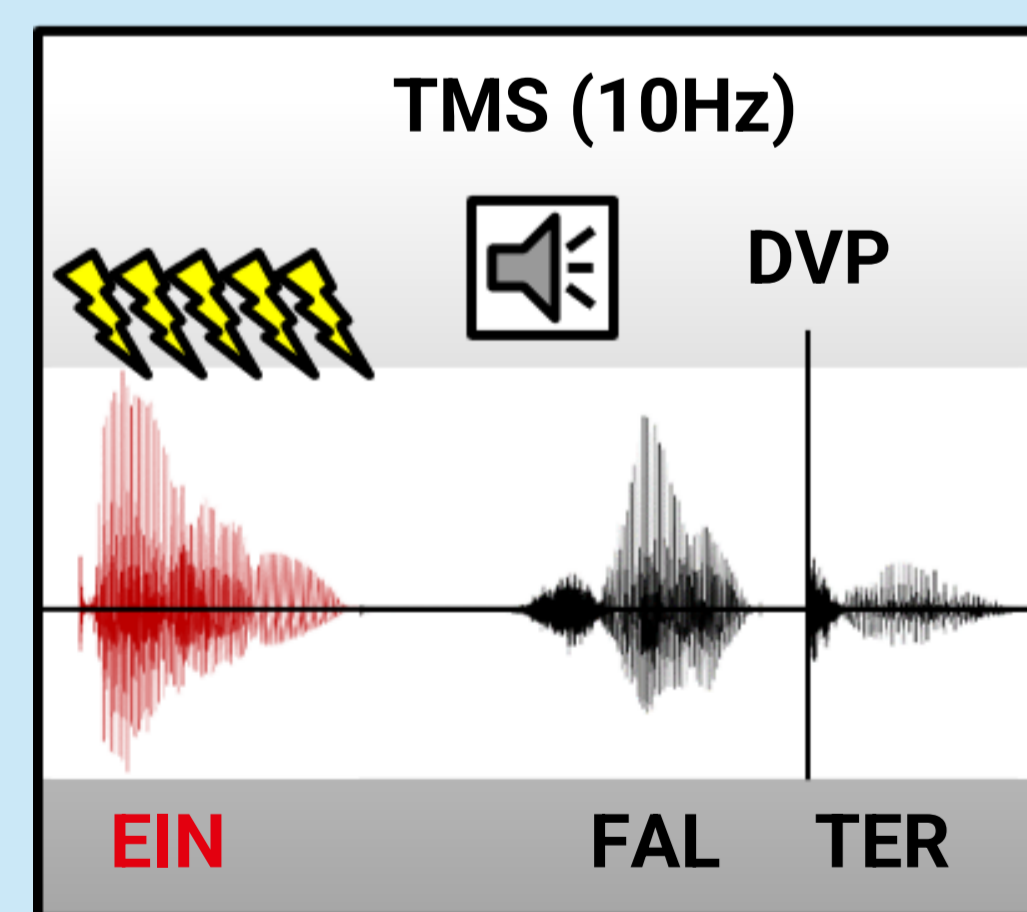
A role of **Broca's area** (BA44) in categorical prediction is supported by fMRI data [3], but causal evidence for this claim is still missing.

We employed **TMS** to interfere with **BA44** functioning at the **predictive stage**. Disrupting BA44 functioning should reduce the ESN effect, since in the absence of predictions categories leading to **grammatical** and **ungrammatical** phrases would be **equally unexpected**.

Methods

We constructed German two-word utterances, which could be **grammatical** (e.g., EIN FALTER, *a butterfly*) or **ungrammatical** (e.g., *EIN FALTET, *a folds*, [1]), with the second word respectively matching or not the **categorical prediction** triggered by the **first word**.

29 native German speakers listened to the two-word items, while **EEG** signal was recorded. ERP analysis was time-locked to the divergence point (DVP) of the second word (e.g., FAL$_{[DVP]}$TER, FAL$_{[DVP]}$TET).

TMS was delivered at the onset of the **first word**, to interfere with the generation of a categorical prediction.

TMS (10Hz)
DVP
EIN   FAL   TER

TMS conditions:
1. **Broca's area** (BA44);
2. **Sup. Parietal Lobe** (SPL);
3. **Sham** (vertex).

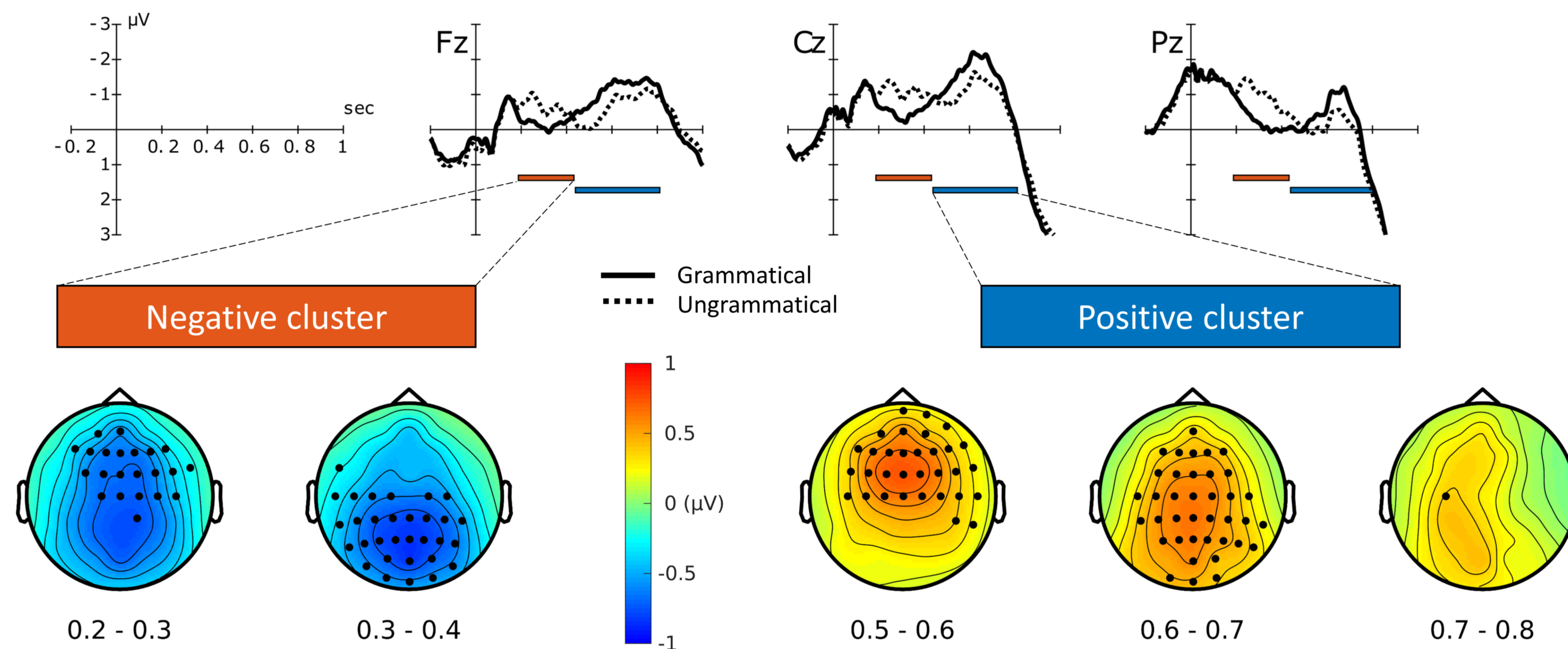Cluster-based permutation tests were conducted [4].

By employing state-of-the-art modelling [5], we further **correlated** the TMS-induced **electrical field in BA44** with the **ESN reduction** relative to the sham condition.

Expected results:
1. Grammaticality*TMS interaction
2. Significant correlation between ESN reduction and TMS-induced electrical field in BA44
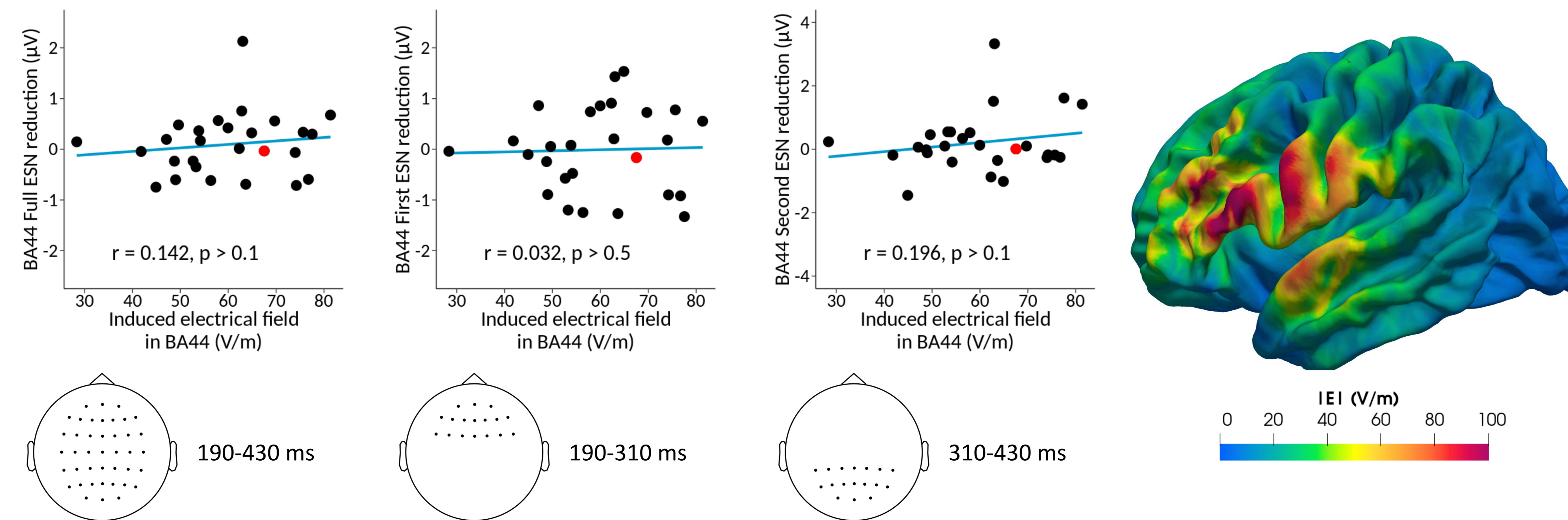
Results

Main effect of Grammaticality

Grammatical
Ungrammatical

Negative cluster
Positive cluster

0.2 - 0.3   0.3 - 0.4   0.5 - 0.6   0.6 - 0.7   0.7 - 0.8

Cluster-based permutation tests revealed a **main effect of grammaticality**, with a significant **early negative cluster** (ESN, approximately from 190 to 430 ms, $P < 0.0005$, cluster-corrected) followed by a **late positive cluster** (approximately from 440 to 800 ms, $P < 0.0005$, cluster-corrected). The **grammaticality*TMS** interaction was **not significant** ($P > 0.5$, cluster-corrected).

Correlation between ESN reduction and induced electrical field in BA44

$r = 0.142, p > 0.1$ $r = 0.032, p > 0.5$ $r = 0.196, p > 0.1$

190-430 ms   190-310 ms   310-430 ms

|E| (V/m)   0 20 40 60 80 100

We calculated the difference between the ESN of BA44 and sham sessions in three ROIs and time-windows (displayed under the scatter plots): Full ESN, First and Second halves of the ESN. **No significant correlation** was found between the **induced electrical field in BA44** and **reduction**, relative to the sham, of the **Full ESN** ($r = 0.142, p > 0.1$, $BF_{01} = 3.302$), the **First ESN** ($r = 0.032, p > 0.5$, $BF_{01} = 4.134$) and **Second ESN** ($r = 0.196, p > 0.1$, $BF_{01} = 2.648$) from BA44 sessions. 27 subjects were included in the correlation analysis. Field reconstruction of data from a single subject, highlighted in the scatter plots, is displayed on the right.

Discussion

Our study replicated the presence of the **ESN** [1], followed by a **late positivity**. This pattern mirrors the ELAN-P600 effect reported with longer stimuli.

Contrary to our hypothesis, TMS over BA44 at the predictive stage did not affect the amplitude of the ESN. Our study **does not provide evidence for a causal role of Broca's area** in **categorical prediction**.

Our findings are compatible with a **bottom-up** role of Broca's area in syntactic composition [6], with an involvement at a later stage when syntactic rules can be evaluated on two words [7].

Further studies are needed to address the involvement of Broca's area in syntactic prediction and integration.

Preprint

The preprint of this study is available on bioRxiv: doi: https://doi.org/10.1101/2021.04.14.439631

Scanning the QR code or clicking on the following short URL link will direct you to the preprint.

Short URL: https://bit.ly/349RQgd

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