THE ROLE OF BROCA'S AREA IN SYNTAX: A TMS STUDY ON WRITTEN GREEK LANGUAGE

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Abstract

A number of recent papers have addressed the potential of transcranial magnetic stimulation (TMS) to interfere with linguistic processes or speech production. In this paper we present an experiment with TMS to clarify the role of Broca's area in syntactic processing. An experimental paradigm contrasted sentences that require syntactic and semantic decisions on written Greek language. We found a clue of selective priming effects on syntactic decisions but not on semantic decisions. Our results provide evidence of the involvement of Broca's area in syntax.

Keywords: TMS, syntax, Broca's area, Greek language

Introduction

In the last 20 years there has been an explosion of studies into the neural basis of language in human brain (Price, 2012). A number of papers have addressed the potential of **t**ranscranial **m**agnetic **s**timulation (**TMS**) to interfere with linguistic processes or speech production (Epstein, 1998 – Pascual-Leone et al, 1991). TMS can be used to identify the language dominant hemisphere by targeting the language relevant areas in temporal, parietal or prefrontal cortex of both sides (Mottaghy et al, 2006). It is generally accepted that TMS or rapid TMS (rTMS) applied to a circumscribed cortical area has not only a local effect but can also influence functionally connected brain regions. TMS therefore seems to be able to modulate areas which are remote from the site of stimulation. Single pulse TMS and rapid TMS have been used in many studies, such as in speech arrest (Pascal-Leone et al, 1991), in safety of TMS studies (Pascal-Leone et al, 1993), in human brain research (Hallet, 2000), in syntax (Sakai et al, 2002), in chronic aphasia (Naeser et al, 2005), in picture naming studies (Mottaghy et al, 2006), in artificial syntax processing (Uddén et al, 2008).

The specialization of syntactic processing in human cognitive systems is one of the central issues in neuroscience (Sakai et al, 2002). Broca's area seems to play a major role in syntax of language. Previous imaging studies have identified cortical regions, like Broca's area, which are involved in syntactic processing (Embick et al, 2000, Hashimoto & Sakai, 2002, Peterson et al, 2003). The narrowest definition of Broca's area is the left pars opercularis (F3op, Brodmann's area [BA] 44) and the left pars triangularis (F3t, BA 45), a part of the third frontal convolution (F3) or the left inferior frontal gyrus (IFG) (Sakai et al, 2002).

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The purpose of this study is to determine if TMS over Broca's area has any effect in taking a linguistic decision. By that way we aim to clarify the essential role of Broca's area in syntax. The experiment uses Greek language stimulus and is based on the experimental setup of Sakai et al (2002).

Materials & method

Participants: Six (6) right-handed, healthy and native Greek speaking adults volunteered to participate in this study (5 female and a male subject). None of the subjects used any medication, had a health problem history or any kind of metallic implement. All subjects had normal or corrected to normal vision. The local Ethics Committee at the Patras University Hospital approved the experiment. All subjects gave written informed consent. Due to technical problems, three (3) of the participants had to be excluded from the analysis of our results. The subjects were asked to respond to the optical stimulus by pressing one of two buttons as quickly as possible while ensuring correct responses.

Stimulus Material: 20 normal sentences, 20 sentences with syntactic errors and 20 sentences with semantic errors, having the same number of syllables and syntactic type VERB-OBJECT (no need for SUBJECT in Greek) were presented to the subjects of the study. The stimulus was written in Turbo Pascal n.12 (DOS environment – Windows 98) in a special PC program, which was especially made for this study. This program was able to collaborate with a single-pulse Magstim 200 TMS, so the PC was providing signal to the Magstim when to make stimulation (TMS). The stimulus (sentences) was presented on black screen, written in white letters. A mouse was attached to the PC with two (2) colored buttons, a green one and a red one.

TMS was delivered through a cycle 9 cm diameter coil. TMS intensity was set at 45% at a rate of 0.3 Hz and duration about 1 sec. The coil was placed over the left hemisphere at a distance 10% from the ear for T3 point and 20% over for F7 point. The center of the coil was over F7 point.

Experimental procedure: We tested two language tasks which require linguistic decisions and were performed in separate sessions. The first task was a syntactic language task (**SynT**), where subjects had to judge whether the sentences were either *syntactic normal* (**N**) *or not* (**A**). The other task was a semantic language task (**SemT**), where the participants had to judge whether the sentences were either semantic normal (**N**) or not (**A**). In both tasks, we presented normal sentences and abnormal sentences. The participants had to read the sentences in silence and then decide as fast as they could if the sentence was N one or A.

We focused on a universal aspect of syntactic operations that is common to both English and Greek: a distinction between transitive verbs and intransitive verbs. This distinction is critical in sentence comprehension because the type of verb in a sentence determines the syntactic structure of it (Smith & Wilson, 1979). Subjects were explicitly instructed to detect a syntactic anomaly, but not instructed to pay attention to the type of the verb in the sentence. In the Sem Task, subjects judged whether the sentences were either semantically normal or anomalous while presented sentences were syntactically correct as to the usage of the verb. We focused on a lexico-semantic relationship between a noun and a verb. Normal sentences were identical among these tasks, so we tested each task in separate sessions so that the TMS effect on judging whether a normal sentence is syntactically correct can be dissociated from that on judging whether the same sentence is semantically correct. Alternatively, anomalous sentences had only one type of linguistic error in each task. Therefore, these stimuli formed minimal pairs for both intra-task pairs (N and A sentences) and inter-task pairs (anomalous sentences for Syn and Sem Task). Sakai et al (2002) named this experimental design a minimal-pair paradigm.

In every task there were 20 normal sentences, 20 semantically abnormal for the SemT and 20 syntactically abnormal for the SynT. Every time a normal sentence was presented on the screen, the subject had to press the green button of the mouse (which was attached to the PC): in case of an abnormal sentence, the subject had to press the red one. The PC program estimated the time since the sentence was on screen until the time the person made her decision. This time is called reaction time (**RT**). Event-related TMS was delivered over Broca's area at a specific timing, which was called *Real Condition* (**R**). As a control to the R condition, we presented recorded discharge click without concomitant TMS at the same volume and timing, just like the R condition: that condition was called *Sham Condition* (**S**). So, the only difference between those two conditions was the presence or not of the TMS. TMS was delivered 150 ms after the onset (T=150 ms).

We chose to deliver TMS at the time of 150ms after the onset because of the results of Sakai et al (2002). When TMS was delivered at T=150 ms, ΔRTs were significantly negative for both sentence types in the Syn Task but not for the Sem Task. When TMS was delivered at T=0 ms or T=350 ms ΔRTs were not significantly different from ΔRT=0 (p>0.1).

Results

The subjects performed the SynT and SemT at the accuracy of 100% across all individuals and conditions.

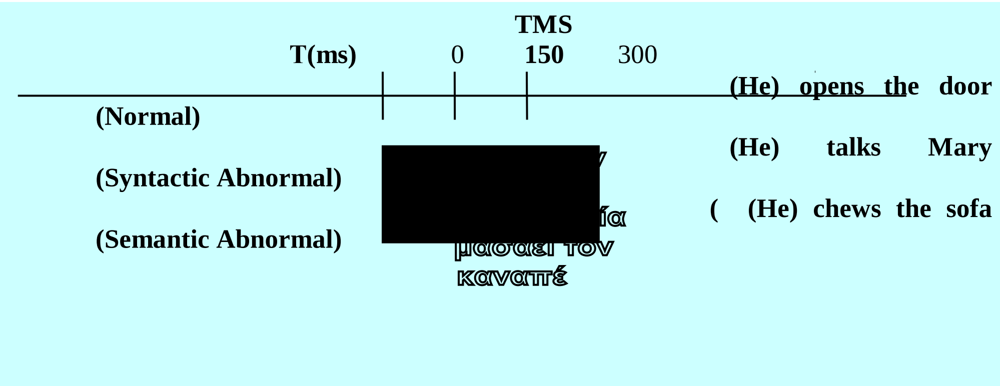

Figure1. TMS was delivered at 150ms from the presentation of the sentence. Normal sentences were the same in both tasks (SynT & SemT)

We separately analyzed the two conditions of TMS (***R****eal Condition* & ***S****ham Condition*) for each task (Syntactic Task-SynT & Semantic Task-SemT). We also analyzed the Reaction Time (RT) for both R & S conditions and we found out the difference of RT (ΔRT) for N and A sentences in the SynT and SemT.

ΔRTs were **positive** for N and A sentences of SemT: so ΔRTs in the SemT were not different from ΔRT=0 (according to *one population t-test* P>0.5). ΔRTs for N sentences of SynT were also **positive** (P>0.5), but ΔRTs for A sentences of SynT were **negative**: so ΔRTs in the SynT for A sentences were different from ΔRT=0 (P<0.2).

We also compared:

o ΔRTs between N sentences for both tasks (SynT & SemT): according to *two populations t-test* there was no significant difference (P>0.8).

- ΔRTs between N and A sentences for SemT: according to *two populations t-test* P>0.9 (no significant difference).
- ΔRTs between N and A sentences for SynT: according to *two populations t-test* **P<0.25** (close to significant difference).
- ΔRTs between A sentences for both tasks (SynT-SemT): according to *two populations t-test* **P<0.25** (close to significant difference).

	Syntactic Task				Semantic Task			
Subject	N sentences (ΔRT)	**Mean ΔRT** (ms)	A sentences (ΔRT)	**Mean ΔRT** (ms)	N sentences (ΔRT)	**Mean ΔRT** (ms)	A sentences (ΔRT)	**Mean ΔRT** (ms)
A	8.82± 17.71		-21.92± 40.33		103.15± 47.0		101.58± 39.38	
B	189± 70.01	**51.24± 70.75**	-28.18± 47.62	**-50.85± 25.86**	68.37± 8.83	**38.67± 48.14**	-35.02± 41.53	**31.14± 39.49**
C	-44.46± 63.32		-102.47± 11.50		-55.50± 21.69		26.88± 52.08	
		P= 0.54419		**P= 0.18823**		**P= 0.5061**		**P= 0.51293**

Table 1: ΔRTs of the subjects after TMS for the SynT and the SemT

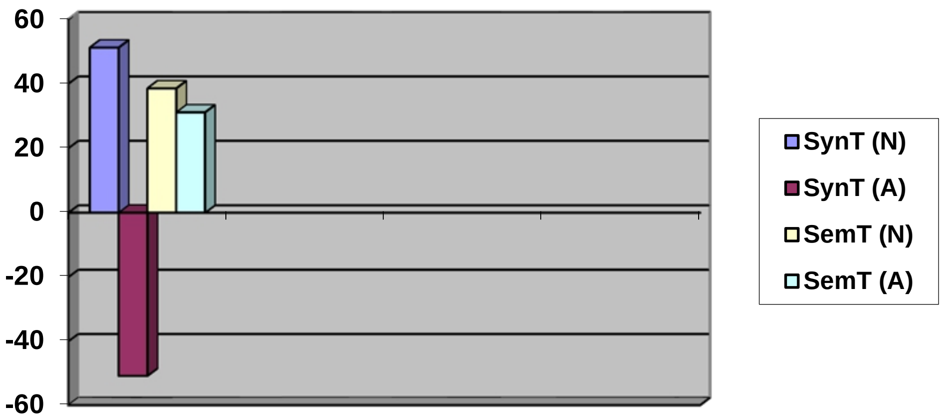

Figure2. The results of the study: TMS over Broca's area seems to have an effect on SynT (for A sentences)

Conclusion

Our study shows two basic results:

a) Event-related TMS seems to reduce RTs in SynT but not in SemT and

b) The effect of TMS was only observed during abnormal syntactic processing and not during abnormal semantic processing.

These results are consistent with previous functional imaging studies which have implicated selective activation of the left F3op/F3t during syntactic processing in comparison with semantic processing (Dapretto and Bookheimer, 1999, Ni et al, 2000). Also Stromswold et al. (1996), Embick et al (2000), Moro et al (2001), Indefrey et al (2004), Kinno et al (2014), Bernal et al (2015) have mentioned the crucial role of Broca's area in syntactic processes and other language processing by using fMRI and PET techniques in their research. In this study we have chosen to use the TMS method instead of a functional imaging method because it creates plasticity on the brain, while neuroimaging techniques (fMRI, PET) record brain activity, measuring hemodynamic changes (Price, 2012).

Sakai et al (2000) use rTMS in a similar linguistic study to ours. We find out reduction of ΔRTs in abnormal syntactic sentences but not to normal sentences as they did. We have also chosen to stimulate just at 150 ms and not to 0 ms or 350 ms on set as they did, in order to reduce stimulation sessions because of our inexperience with TMS and linguistic tasks on normal subjects.

We found no significant difference in our results. This might be due either to the small number of subjects (three) or the sex used on this research. There is probably need for more subjects to make significant results. The subjects used in our study were women while Sakai et al (2002) used three male subjects in their study. Hartshorne & Ullmann (2006) suggest that gender factor is very important in any kind of linguistic processes and research.

Carreiras et al (2012) used TMS to investigate the involvement of Broca's area in morphosyntactic processing, while working memory and cognitive control demands are low. They presented word pairs, not sentences as we did, that could either agree or disagree in grammatical gender or number while stimulating Broca's area and other regions. Stimulation over Broca's area significantly reduced the advantage for grammatical relative to ungrammatical word pairs. The interaction between grammaticality and stimulation was specific to that region (Broca's area), suggesting a clear involvement of the region to the morphosyntactic process. Grodzinsky and Santi (2012) by using event-related fMRI imply that an alternative or modified functional account of Broca's area is required.

Many recent studies use TMS over Broca's area to demonstrate the casual role of this region in the encoding of grammatical gender (Cattaneo et al, 2009), as also to provide evidence that this region contributes to word recognition speed (Zhu et al, 2015).

Price (2012) suggests that the next 20 years will need to focus on understanding how different regions interact with one another and how specialization for language arises at the level of distinct patterns of activation in areas that participate in many different functions.

We strongly believe that TMS studies give possibilities to research into the localization, specialization and interaction of different brain regions in language.

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