Use Of Magnetic Stimulation For Functional Analysis Of Speech and Language Processing

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Introduction

Magnetic stimulation was introduced in the 1980's as an alternative to the relatively more uncomfortable electrical stimulation of the central nervous system(Barker et al. 1987). By inducing a magnetic field which can penetrate tissues, either nerves can be stimulated peripherally, or neural tissues can be stimulated at the cortex. Central nervous system motor nerve conduction times can be determined by stimulating nerve roots and the motor cortex. Thus, it is a useful technique for identifying central nervous system demyelination(Hallett & Cohen, 1989) or central control abnormalities. This technique has also been used to map cortical representation of various muscles(Cohen et al. 1990a) and to study reorganization in cortical representation as a result of peripheral changes, such as following limb amputation(Cohen et al. 1991a; Brasil-Neto et al. 1993) and central changes, such as stroke, hemispherectomy(Benecke et al. 1991), or spinal cord injury(Cohen et al. 1991; Topka et al. 1991). More recently magnetic stimulation has been used to disrupt cortical function transiently for the study of the temporal and spatial organization of cognitive processes. The purpose of this paper is to review the use of this technique for studying cognitive processing and to present some examples of how this technique might be applied for analyzing psycholinguistic processes in speech and language.

Selection of Magnetic Coils for Peripheral or Cortical Stimulation

A magnetic coil contains many turns of wire. When current flow changes rapidly in the wire, a magnetic field is induced perpendicular to the plane of the coil for a short duration. This magnetic field will induce currents flowing in tissues parallel to the plane of the coil. These currents activate tissues(Maccabee et al. 1991; Roth et al. 1990; Roth et al. 1991).

Two coil designs have been used most frequently; a round coil and a smaller 2 coil system known as the figure eight coil. The round coil produces an electrical field which is greatest at the edge of the coil and negligible at the center(Cohen et al. 1990b). This coil has a greater depth of stimulation than the figure eight coil(Roth et al. 1990) and as such would be most useful for stimulation of deep structures such as the laryngeal nerves, when held on the neck. The figure eight coil has a more focal electric field which is greatest at the confluence of the two coils in the center, and less at the outer edges of the coils(Cohen et al. 1990b). The induced field has less depth and area of stimulation making it more useful for cortical stimulation and mapping(Roth et al. 1991) because it is less likely to induce a response in cranial nerves as they emerge into the face and neck. Because the speech motor control system involves cranial nerves which emerge from the brain close to the skull, muscle responses could result either from direct peripheral nerve stimulation or via stimulation of the corticobulbar tract. The depth and spread of the induced magneto-electric field, therefore, are of concern when attempting to assess corticobulbar pathways to the vocal tract musculature(Haghighi & Estrem, 1991) and care must be taken to separate responses due to peripheral nerve stimulation, from those due to cortical stimulation. Thus, when the round coil is placed in the region of Broca's area, the induced field may be large enough to involve the trunk of the vagus, and ipsilateral muscle responses to peripheral nerve stimulation may be difficult to distinguish from ipsilateral responses due to corticobulbar stimulation.

Potential Diagnostic Uses

Clinical tools are needed for determining the nervous system control of speech, language and voice function and to diagnose the location and type of abnormalities in patients with idiopathic voice, speech and language disorders. In vocal fold paralysis, if nerve conduction is slowed but cortical responses are normal once the peripheral nerve conduction time is subtracted, then the myelin sheath of the peripheral nerve may have been affected. On the other hand, if the nerve conduction time for the peripheral nerve is within the normal range, while responses to cortical stimulation are delayed, then injury or disease may have involved the motoneuron pool or the corticobulbar tract. Few normative studies have provided data on this technique when used for the vocal tract musculature. Thumfart et al. (1992) used magnetic stimulation to elicit a muscle action potential in the thyroarytenoid muscle and determine recurrent laryngeal nerve response latencies. They placed the stimulator, "approximately 2 cm behind and 6 cm above the external auditory canal for stimulation of the nerves at their cisternal part." (page 631) (Thumfart et al. 1992). Thyroarytenoid muscle mean response times in 52 healthy subjects were 5 ms, a standard deviation of 0.7 ms and a range from 4 to 6.6 ms. They also reported that magnetic stimulation on the neck produced a muscle action with a latency of 6-8 ms in the thyroarytenoid muscle. Thus, muscle responses to stimulation at the cisternal location most likely were produced by peripheral nerve stimulation at a location closer to the larynx than during neck stimulation. These responses, however, were produced with a TECA coil with a diameter greater than 9 cm. Further study is needed, therefore, before this technique could be used for diagnostic evaluation of peripheral nerves and in central injury or disease affecting central vocal tract neural control.

Another potential use of magnetic stimulation is to determine the cortical organization for the vocal tract musculature. It is well recognized that the limb musculature is only represented in the contralateral hemisphere as evidenced from contralateral unilateral paralysis following middle cerebral artery infarct. Transcranial magnetic stimulation has supported this for limb musculature(Cohen & Hallett, 1988). However, the effects of cerebrovascular accidents on the facial and vocal tract musculature are usually transient, suggesting either that 1) reorganization or plasticity following brain injury are more likely for these structures, or, 2) some degree of bilateral representation of the vocal tract musculature is present in each hemisphere. This can be assessed by stimulating the motor areas of the cortex and evaluating the latency and consistency of ipsilateral and contralateral muscle responses.

Some unexpected differences have been found thus far in the degree to which facial and neck musculature are represented either contralaterally only or bilaterally. Cruccu et al. (1990) evaluated muscle responses in both the upper and lower facial muscles. Using bipolar concentric needle electrodes, they found that the same unit in the right frontalis muscle was activated by both right and left transcranial stimulation while a single motor unit in the right mentalis muscle was only activated by transcranial stimulation in the left hemisphere. Others have reported bilateral responses in the tongue musculature, and to a lesser degree in the lower facial muscles(Meyer et al. 1990). Further, some of the neck muscles may have bilateral cortical representation(Berardelli et al. 1991). More systematic evaluation is needed of the degree of bilateral cortical representation of the vocal tract musculature.

Because the cranial nerves may be stimulated directly (peripherally) during transcranial stimulation, ipsilateral muscle responses must be interpreted with caution. They could be due to peripheral nerve stimulation rather than due to the presence of ipsilateral corticobulbar pathways. Only when ipsilateral responses are the same latency or later than contralateral responses can they possibly be considered due to corticobulbar excitation(Berardelli et al. 1991).

Functional Analyses of Cognitive Processing

Some have used transcranial magnetic stimulation for analyzing the temporal and spatial distribution of various cognitive processes in normal humans(Amassian et al. 1992; Amassian et al. 1993; Cracco et al. 1990; Amassian et al. 1990). Transcranial stimulation has been demonstrated to have both faciliatory and inhibitory effects on cortical function(Valls-Solé et al. 1992; Pascual-Leone et al. 1992; Brasil-Neto et al. 1992; Pascual-Leone et al. 1992; Cohen et al. 1991b). In addition, transcranial stimulation can alter the reception of sensory stimuli, their recognition and the speed and accuracy of motor responses. Some of the research demonstrating how this technique might be used for analyzing cognitive processing is reviewed below.

Recognition of Sensory Stimuli: Amassian et al. (1990) presented a single magnetic stimulus to the scalp supposedly overlying the calcarine fissure, the primary visual cortex, at specific time intervals after brief presentations of letters on a screen. They found they could block visual perception entirely using this technique; the subjects reported seeing nothing or a blur when magnetic stimulation was between 80 and 100 ms after letter presentation. They concluded visual perception of the letters was inhibited by magnetic stimulation and that neural activity subserving letter recognition is completed within the visual cortex 140 ms after stimulus presentation. More recently, Amassian et al. (1993) conducted several experiments examined the interference with letter recognition when they presented two stimuli at precise intervals. First, they presented magnetic stimuli over the calcarine fissure simultaneous with letter presentation (0 ms) and 50 ms after visual presentation. Although single stimuli did not have an effect when presented at either 0 or 50 ms, the sequence of the two stimuli reduced reporting accuracy from > 90% to less than 40%. This suggested that the first stimulus had an effect on visual information processing for up to 50 ms. Similarly, although single stimuli did not have an effect when presented at either 60 or 150 ms,by presenting paired stimuli at 60 and 150ms after the visual target they were able to depress the proportion of letters perceived correctly to 33%. When the conditioning pulse was at 60 ms after the stimulus presentation, then the second pulse disrupted perception only if it occurred less than 160 ms after the visual stimulus presentation. They interpreted the results as suggesting that when the first stimulus was delivered, it preceded the arrival of visual information at the cortex and delayed the subsequent transmission of stimuli from the calcarine cortex by about 50-60 ms. The finding that the second pulse disrupted perception only if it occurred before 160 ms, suggested that the first pulse delayed cortical transmission for up to 60 ms, because visual perception could be disrupted with a single stimulus mostly at 100 ms(Amassian et al. 1990).

Cohen et al. (1991b) found that the detection of somatosensory stimuli was attenuated when magnetic stimulation was 200 ms prior to stimulus presentation. Detection was entirely blocked when the magnetic stimulation was simultaneous or 20 ms after the stimulus, and no effects were found when magnetic stimulation was 200 ms after stimulus presentation. Seyal et al. (1992) also studied the suppression of cutaneous perception using magnetic stimulation over the sensori-motor cortex. They varied the time of finger stimulation after a magnetic pulse and found perception was suppressed from 30 to 90 ms after magnetic stimulation and returned to control levels 300 to 400 ms after the magnetic pulse. They found that errors in the perception of the stimuli occurred up to 300 to 400 ms after the magnetic pulse suggesting that the effects of magnetic stimulation on sensory processing persisted for a considerable period. When the transcranial magnetic stimulation followed the cutaneous stimulation by about 20 to 30 ms, perceptual errors occurred. Both studies(Seyal et al. 1992; Cohen et al. 1991b) suggested that the time of arrival of afferent information at the cortex was 20 ms.

Inhibiting, Disrupting and Facilitating Motor Responses: Day et al. (1989) demonstrated in a simple reaction time task that when a magnetic stimulus was delivered to the brain over the motor cortex 100 ms after a tone, then the latencies of agonist EMG bursts were increased by 50 ms. This again suggested that magnetic stimulation produced an inhibition of cortical function rather than an excitation. Amassian et al. (1991) also reported that sequential movements were both delayed and disrupted when they stimulated over the supplementary motor area, suggesting a difference in the motor control properties of the motor cortex and the SMA.

Facilitation of motor responses with magnetic stimulation has also been found. Pascual-Leone et al. (1992) reported shorter reaction times when lower intensities of magnetic stimulation, those subthreshold for a muscle response, were delivered to the motor cortex during a simple reaction time task. In contrast, suprathreshold stimulation levels, those evoking a motor response, increased reaction times. During another study, when subthreshold stimuli were presented to the motor cortex contralateral to the responding hand, reaction times to sensory stimuli were shortened by up to 30 ms maximally when the stimulation was delivered 10 ms after the sensory stimulus(Pascual-Leone et al. 1992). Finally, using a conditioning paradigm to evaluate the response to a second stimulus after a first, different periods of inhibition and facilitation were found following low and high intensity magnetic stimulations(Valls-Solé et al. 1992). At low stimulation levels, a period of inhibition was found lasting from 5 to 40 ms which was followed by a period of facilitation from 50 to 90 ms after the initial stimulus. At high stimulation levels, a period of facilitation lasted from 20 to 60 ms followed by an inhibitory period from 60 to 150 ms. These results suggest that both inhibition and facilitation of motor cortex processing can occur as a result of magnetic stimulation which may depend, in part, upon the time and strength of cortical stimulation.

Spatial and Temporal Mapping of Psycholinguistic Processes: Recently, attempts have been made to use magnetic stimulation to locate language processing in the brain. Amassian et al. (1990) used magnetic stimulation on the right and left sides, presumably over Broca's area, during speech syllable repetition. They found they were able to disturb speech, producing a vowel prolongation in the middle of a word, or disrupting the transition to the following phoneme. However, when a subject was silent they were unable to elicit vocalization. They also recorded surface EMG from small disc electrodes placed 2 cm apart on the paramedian line between the sternum and the thyroid cartilage, most likely picking up signals from the sternohyoid and sternothyroid muscles. Short latency responses from 6 to 8 ms were elicited in the muscle recordings when stimulation was close to the precentral gyrus. Longer latency responses from 13 to 20 ms were elicited when stimulating over the region presumed to be Broca's area. Amassian et al. (1990) interpreted these results as suggesting two different centers involved in speech production; the planning region being Broca's area while the final stages of motor output being over the precentral gyrus.

We suggest another interpretation to explain these results. The former latencies, between 6 and 8 ms, are similar to peripheral nerve conduction times found by Thumfart and most likely reflect direct nerve stimulation. The later responses, from 13 to 20 ms, most likely reflect corticobulbar responses. The authors also reported finding later responses from 40 to 60 ms. We suggest that these most likely represent R2 responses as a result of stimulation of afferents from the superior laryngeal nerve(Ludlow et al. 1992). They did not report any differences, however, in their elicitation of these responses or of speech disruption, when stimulating the left or right hemispheres.

Pascual-Leone et al. (1991) used repetitive transcranial magnetic stimulation at 8, 16 and 25 Hz for 10 s over the right and left hemispheres in 6 patients with epilepsy who had had the intracarotid amobarbital Wada test, demonstrating language in the left hemisphere. Complete anarthria was induced in all six after 4 to 6 s of left hemisphere stimulation in the pre-central representation areas for the lips, mouth and throat. Right sided stimulation did not lead to speech arrest or counting errors at any of the stimulation points, although a tremulous dysarthric voice occurred.

More recently, Claus et al. (1993) used repetitive magnetic stimulation over the temporo-parietal cortex at 50 Hz for 500 ms starting 0 to 15 ms after a sentence appeared on a screen. They compared the subjects' abilities to repeat the sentence following stimulation on the right and left sides. The results of the reading test did not demonstrate laterality. Reading errors during right and left stimulation were significantly greater with stimulation on the left for only one series of sentences. These tests of language laterality, then, were neither sensitive nor reliable for determining the language dominant hemisphere.

The types of language tasks that were selected, however, might explain why Claus et al. (1993) did not find a clearcut left hemisphere effect. Blood flow studies have demonstrated bilateral activation of the two hemispheres in the precentral and motor cortex(Ingvar, 1983; Ingvar & Schwartz, 1974; Lassen et al. 1978; Lassen & Larsen, 1980) and the supplementary motor areas during speech in normal speakers with no evidence of left hemisphere dominance for automatic speech such as counting(Larsen et al. 1978). Further, different language processes of phonology, syntax and semantics seem to have varying degrees of lateralization to the left hemisphere(Levy et al. 1977). Right hemisphere language functioning was studied extensively in patients who underwent complete cerebral commissurotomy for the relief of intractable epilepsy(Zaidel, 1978b; Zaidel, 1978a). Specially fitted contact lenses assured occlusion of one visual field and allowed visual stimuli to be presented to one hemisphere during lengthy language testing of each hemisphere(Zaidel, 1978a). In these split brain patients, no reports of right sided speech expression occurred; speech was only elicited from stimuli presented to the left hemisphere. However, the right hemisphere was found to have good language comprehension; verbs and nouns could be easily understood in both written and spoken forms. The right hemisphere could understand sentences and phrases largely from their vocabulary and not from their syntactic structure. The right side could not perform letter-to-sound matching or pairing. For the right hemisphere, no reports have demonstrated that it is capable of phonetic analysis, rhyming or recognizing meaningless consonant-vowel syllables(Levy et al. 1977). Only the left hemisphere could perform speech sound discrimination and syntactic transformation while both hemispheres could perform semantic interpretations of language material(Zaidel, 1978b). Therefore, left hemisphere dominance might be more likely to be identified if the phonological aspects of language were tested.

Claus et al. (1993) also attempted to replicate the findings of Pascual-Leone et al. (1991) by stimulating repetitively on the left and right sides for 8 s during counting in 5 right handed normal subjects. They were unable to replicate Pascual-Leone et al.; no speech disruptions or counting errors occurred in the 5 subjects when stimulated in either hemisphere. The explanation they offered was that Pascual-Leone et al may have induced bilateral laryngeal muscle activation. Bilateral laryngeal muscle contraction could produce a glottal stop or a prolonged vocal fold opening, disrupting speech. Thus a peripheral speech disruption may have interferred with the subjects' production rather than an interference with language processing. Claus et al., however, did not provide any explanation of why laryngeal muscle responses might be greater with stimulation on the left side. Another possibility, could be that the stimulation intensity used by Claus et al., was only 1 Tesla while that used by Pascual-Leone et al. (1991) was > 1.5 T. Claus et al. (1993) reported error rates of between 10 and 50% suggesting that their stimulator may not have been as effective as that used by Pascual-Leone et al. (1991).

To avoid some of these difficulties, the following procedures might be helpful when attempting to find right left hemispheric differences in language function:

- control the type of language knowledge being tested; semantic knowledge or lexical retrieval may be redundant or diffusely represented in the brain, while phonological skills may be confined to the left hemisphere
- control the duration and spatial presentation of visual stimuli to the brain so that it will be confined to the hemisphere being tested, and
- control the type of response being requested, independent from the language processing aspects of the task.

We will describe our findings in a normal speaker as an example of how magnetic stimulation can be used for speech and language investigation. The subject was a 51 year old male volunteer. He had no history of speech and/or language disorders and was within the normal range on neurological examination. He was right handed, a monolingual native English speaker and naive to the purpose of the study. Our purpose was to determine if different stages of task performance could be identified for visual stimulus recognition, for naming such stimuli, for phonological processing, and for responding to such stimuli.

Visual Recognition

The subject was seated in a dental chair and stimuli were projected onto a white wall 5 ft. in front of him using fast shutter controls on two Constant Illumination Tachistoscopes Model #42011 (LaFayette Instrument Company, LaFayette, Indiana). Tachistoscopic presentation was used to control presentation of the target stimuli to one visual field. A specially designed microprocessor controlled the intervals between each of the tachistoscopes and the presentation interval before the magnetic stimulation following presentation of the target visual stimulus. For the visual recognition task, a fixation point, a small round dot, was presented in the center of the visual field for 500 ms, then a line drawing of a familiar object was presented to one visual field for 20 ms. The subject was asked to respond by naming the stimulus as quickly as possible. Magnetic stimulation was at 100 % of stimulator output using the round 9 cm. Cadwell coil. Stimulation was presented 100 ms after presentation of the target stimulus, which was before the subject was able to respond. For each stimulus location, between 10 and 40 trials were presented. The visual field of presentation was randomly ordered and counterbalanced, with half the line drawings presented to the contralateral visual field, and half to the ipsilateral visual field. The line drawings were all common objects and frequent monosyllabic words which the subject was familiarized with before the experiment so that he knew what name was expected for each object (e.g.. chair, hair, car, star, bed, head, pen, ten, bear, pear, plane, train, duck, truck, hat, cat, mop, top, tree, three). A total of 45 no stimulation control trials were interspersed in blocks of 10 and one of 5, between stimulations at the various locations. The percent correct naming responses for each stimulation location, when the target was presented to the visual field either contralateral or ipsilateral to the stimulation side, are presented in Table 1.

The expectation was that when the image was presented to the contralateral visual field, visual recognition would be required involving the secondary visual region in that hemisphere before lexical retrieval for eliciting a naming response. When stimulation was in the mid occipital region 100 ms after the presentation of the stimulus, the subject reported that he was aware that a stimulus had been presented but said he did not recognize it. This replicates the findings of Amassian et al. (1990). Stimulation in adjacent regions including the lateral occipital and the supramarginal gyrus were somewhat reduced in accuracy suggesting that transfer of the information from the occipital cortex to the language integration regions in the parietal area had begun by 100 ms after target presentation. The lexical selection aspects of the tasks were not interfered with at 100 ms, however, because fewer errors occurred when stimulation was over the temporal parietal regions in either hemisphere than occurred with stimulation over the occipital regions. Results such as these, therefore, can be interpreted as demonstrating that the lexical access component of the naming task was not occurring at 100 ms. At this time, magnetic stimulation only interfered with visual perception and recognition primarily in the primary occipital cortex.

Table 1. Percentage of correct naming responses during magnetic stimulation 100 ms following target presentation to one visual hemifield on either the ipsilateral or contralateral side from the stimulation side.

Stimulus Location	Visual Field of Target Presentation (Relative to Stimulation Side)		
	Contralateral	Ipsilateral	Total
Mid Occipital	0%	0%	0%
Lateral Occipital	60%	60%	60%
Intermediate between P3 & T3 (Presumed to be the Left Supramarginal Gyrus)	60%	90%	79%
Intermediate between P4 & T4 (Presumed to be over the Right Supramarginal Gyrus)	80%	60%	70%
7 cms. anterior to T3	100%	100%	100%
4 cms. anterior to C3	100%	80%	90%
No stimulation			95%

Visual Naming

Next, in an effort to determine if the lexical access components of the task could be interfered with using magnetic stimulation, we used the same task but varied the time between the target stimulus presentation and the onset of the magnetic pulse from 80, to 100, 120, 150, 200 and 250 ms. For this study, we used the smaller more focal figure eight Cadwell coil at 100% of stimulation output because we wanted to stimulate the region of the supramarginal gyrus without interfering with the recognition of the visual drawings. When using the small coil no hemifield effects were noticed, that is the errors and response delays were equally divided between the contralateral and ipsilateral image presentations which was not the case with the larger coil. Another change made during this task was random presentation of the magnetic stimulation. We noted that when the magnetic stimulation became delayed further past 100 ms, the subject began to wait until the magnetic stimulation occurred before providing a response. To prevent this, we stimulated randomly on 50% of the trials, that is during 10 of 20 trials. The percentage of correct responses at each stimulation latency in the region of the right or left supramarginal gyri, are presented in Table 2.

Table 2. The percentage of correct responses during trials with magnetic stimulation in the region of the left and right supramarginal gyrus at each of six different latencies following target presentation.

Scalp Regions Presumed to be Over the Following Brain Regions	Latency	% Correct	% Delayed
Left Motor Cortex	100	100	0
Left Broca's	100	100	0
Left Supramarginal Gyrus	80	100	0
Left Supramarginal Gyrus	100	80	7.5
Left Supramarginal Gyrus	120	100	0
Left Supramarginal Gyrus	150	87.9	6
Left Supramarginal Gyrus	200	72.7	9.1
Left Supramarginal Gyrus	250	100	0
Right Supramarginal Gyrus	100	90	0
Right Motor Cortex	100	90	0
Right Broca's	100	90	0

The most naming errors and the highest percent of delayed responses occurred when stimulation was at 200 ms in the region of the left supramarginal gyrus. Although these results must be viewed as preliminary, they indicate that this technique may answer some of the questions related to the timing of the lexical retrieval processes; they suggest that retrieval may occur between 100 and 200 ms after stimulus presentation.

Phonological Processing

Studies of the lateralization of language processing most notably in split brain patients, have demonstrated some degree of lexical access and categorical naming in both the right and left hemispheres. Therefore, the lack of right-left differences during the naming task was not unexpected. Studies in split brain patients, however, did demonstrate preferential left hemisphere functioning for phonological processing(Zaidel, 1978b; Zaidel, 1978a). For this reason, a study of rhyming was developed to determine if right left differences could be identified. For this task, two line drawings, one on the right and the other on the left, (for example, a truck on the right and a car on the left) were presented for 2 seconds, followed by a fixation point for 500 ms. Then a target, for example a star, was presented in one visual field, for 50 ms. The subject was directed to press one of two buttons indicating which of the two original line drawings, the one on the right or the one on the left, rhymed with the target presented. In this case the correct response would be the left button, indicating the car. Stimulation with the magnetic stimulator was over the supramarginal gyrus on the right or the left side, between 250 and 350 ms, after presentation of the target. The small figure eight coil was used and no difference in responses were found whether the target was presented in the contralateral or ipsilateral visual field. Stimulation was only on 20% of the trials because otherwise the subject began to anticipate the magnetic stimulation and wait until after the stimulation to produce his response.

Table 3. The frequency of different types of response errors on the rhyming task during magnetic stimulation at scalp positions presumed to be in the region of the left and right supramarginal gyri between 250 and 350 ms after target presentation.

Response Type	Right stimulation	Control	Left stimulation	Control
No response	0	0	0	0
Self correction	0	0	8.7	2.4
Missed the Target	0	0	0	0
Forgot the Choices	0	0	17.4	4.8
Gave Correct Response	94	100	74	93

As the results in Table 3 suggest, errors were more frequent on stimulation trials than during the control trials only during stimulation at scalp positions presumed to be in the region of the left supramarginal gyrus.

As has been suggested by split brain studies, phonological processing seemed to be lateralized to the left hemisphere, while lexical access for naming did not seem to be lateralized to the left hemisphere. The results also suggested that cognitive processing for the more complex phonological task took longer to complete, between 250 and 350 ms, than lexical retrieval for the naming task.

Response Times.

During the phonological study, we also examined the reaction time of the button pressing responses. These latencies ranged from 650 to 1200 ms after presentation of the target stimulus. An automatic timer was triggered at the time of the visual target and the button press response latency was measured in milliseconds. We computed the difference in the reaction times between a control trial immediately preceding a stimulated trial for each of the correct responses. The response times tended to become reduced during stimulation on the left side in comparison with control trials, while no systematic changes in response times occurred during stimulation on the right (Figure 1).

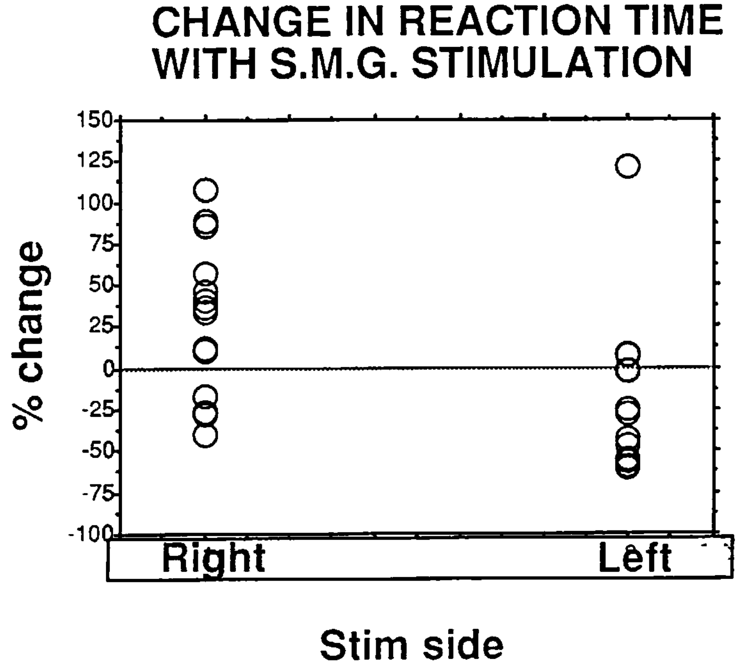

Figure 1. A display of the percent change in response times from an unstimulated trial immediately preceding a stimulated trial, when both resulted in a correct response. A negative value indicates a shorter latency during magnetic stimulation.

Because the response was with the right hand at all times, this result suggested that it had nothing to do with the language processing aspects of the task, but rather to do with the left side being contralateral to the right finger which was used for button pressing. A comparison study when a subject is pressing with the left hand needs to be conducted. At present, we are interpreting this result to suggest that the stimulation was facilitating the motor response for the hand represented on the same side of the brain as was stimulated.

Conclusions

In this paper we have attempted to demonstrate the potential application of magnetic stimulation for analyzing the spatial and temporal aspects of cognitive processes involved in speech and language functioning. The results presented here are only preliminary and will require careful exploration before the techniques can be used for experimentation. However, they do suggest the exciting potential of this tool for analyzing cortical functioning for speech and language. By varying the location and timing of magnetic stimulation, the brain organization of cognitive processing for different tasks can be analyzed. The review of the emerging literature on this technique suggests that magnetic stimulation can have relatively long lasting effects on the level of excitation of neural tissue, up to 200 ms, even though a single pulse may be only 67 μs in duration. In addition, the effects of magnetic stimulation can vary from excitation evoking a muscle action potential, to arrest and disruption of speech. Some studies have also demonstrated response delays, although the responses remain intact, and facilitation of others. These differences seem to depend upon the cognitive processes being studied, the location and timing of stimulation, the stimulus strength and duration. They may also be the result of the secondary effects that the cortical stimulation has on the functioning of other structures under cortical control.

Given these complexities, the use of this technique must be approached with caution. However, transcranial magnetic stimulation seems to have potential for helping us to learn more about speech, voice, and language neural control in normal speakers and in patient populations. It is hoped that this technique will prove useful for mapping the brain control of cognitive processes for speech and language in patients with idiopathic disorders and improve our understanding of brain functioning in disorders such as stuttering, cluttering, and spasmodic dysphonia.

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