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Reduced activation of left orbitofrontal cortex precedes blocked vocalization: A magnetoencephalographic study

Paul F. Sowman[a,*], Stephen Crain[a], Elisabeth Harrison[b], Blake W. Johnson[a]

[a] ARC Centre of Excellence in Cognition and its Disorders, and Department of Cognitive Science, Macquarie University, NSW 2109, Australia
[b] Department of Linguistics, Macquarie University, NSW 2109, Australia

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ABSTRACT

While stuttering is known to be characterized by anomalous brain activations during speech, very little data is available describing brain activations during stuttering. To our knowledge there are no reports describing brain activations that precede blocking. In this case report we present magnetoencephalographic data from a person who stutters who had significant instances of blocking whilst performing a vowel production task. This unique data set has allowed us to compare the brain activations leading up to a block with those leading up to successful production. Surprisingly, the results are very consistent with data comparing fluent production in stutterers to controls. We show here that preceding a block there is significantly less activation of the left orbitofrontal and inferiorfrontal cortices. Furthermore, there is significant extra activation in the right orbitofrontal and inferiorfrontal cortices, and the sensorimotor and auditory areas bilaterally. This data adds weight to the argument forwarded by Kell et al. (2009) that the best functional sign of optimal repair in stutterering is activation of the left BA 47/12 in the orbitofrontal cortex.

Educational objectives: At the end of this activity the reader will be able to (a) identify brain regions associated with blocked vocalization, (b) discuss the functions of the orbitofrontal and inferior frontal cortices in regard to speech production and (c) describe the usefulness and limitations of magnetoencephalography (MEG) in stuttering research.

1. Introduction

Stuttering is a speech disorder of neurological origin. Brain imaging studies have shown that, compared to control subjects, people who stutter (PWS) exhibit significantly different patterns of neural activity during fluent speech production (for review see Brown, Ingham, Ingham, Laird, & Fox, 2005). However, little is known about how activity in the brains of PWS may differ during stuttering compared to their brain activity during fluent speech. This is largely because it is difficult to systematically observe stuttering in brain imaging settings, for several reasons.

In the laboratory it is often the case that PWS stutter less than they normally would. Further, the experimental tasks that are compatible with current brain research methods – e.g. single word or syllable production – typically do not induce enough instances of stuttered speech to include stuttered speech as a condition (e.g. see Salmelin, Schnitzler, Schmitz, & Freund, 2000). Because of this many studies simply discard stuttered epochs from their analysis (e.g. Chang, Kenney, Loucks, & Ludlow, 2009; Salmelin et al., 2000). An alternative strategy is to continuously sample speech during a scanning block and to retroactively correlate brain activations with the degree of stuttered speech (e.g. Braun et al., 1997; Fox et al.,

* Corresponding author. Tel.: +61 2 9850 6732; fax: +61 2 9850 6059.
E-mail address: paul.sowman@mq.edu.au (P.F. Sowman).
URL: http://www.ccd.edu.au (P.F. Sowman).

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2000). Consequently, measurements of brain activations that are directly associated with stuttering instances are rare in the literature (with a few notable exceptions, e.g. Ingham, Fox, Costello Ingham, & Zamarripa, 2000).

We report here a rare case in which we were able to record ~100 instances of both blocked and non-blocked vocalization from a PWS subject. The subject was a participant in a larger magnetoencephalography (MEG) study utilizing a stop signal paradigm to assess the extent of voluntary inhibitory control of vocalization in PWS. The subject was unable to complete the main study due to the high frequency of blocking. However this unusual case provided a unique opportunity to assess brain activity preceding unambiguous instances of vocalization blocking.

2. Method

2.1. Participant

The participant was a 24-year-old right-handed female. Her stuttering began at the age of 7. She has an older sister and uncle with stuttering histories. Her diagnosis of stuttering was confirmed by a speech pathologist and her severity was rated as 4 (on a scale from 1 to 10 where 1 = no stuttering 10 = most severe stuttering imaginable). The subject reported that this severity was typical of her stuttering but that it fluctuates between 3 and 8. At assessment she produced 1428 syllables at a rate of 198 syllables per minute. 3.9% of these syllables were stuttered. Stuttering during assessment consisted of blocks, repetitions of words and fillers. She had no other significant medical history.

This study was approved by the Macquarie University Human Ethics Committee # R06420.

2.2. Stimuli and apparatus

The task used in this experiment was the same Stop Signal task as that described in detail in Etchell, Sowman, and Johnson (2012). As the subject was unable to perform the task due to high frequency of blocking we describe only the ‘Go’ trial part of the experiment which was used in this report. Go trials began with a black fixation cross appearing in the centre of a grey background. The duration of the fixation cross was randomly varied between 1000 ms and 3500 ms after which time, a black letter (either I or O) against a white background surrounded by a green border appeared in the centre of the screen. The letter I appeared on half the trials and the letter O appeared on the other half and their order was randomized. The subject was instructed to respond to the letters by making the sound of the letter O as it would occur in the word “hot” or making the sound of the letter I as it would occur in the word “hit”. Vocalizations were recorded by a directional microphone positioned on the ceiling of the magnetically shielded room above the subject’s head.

The experimental presentation was controlled by the Presentation software package (Presentation 14.4, Neurobehavioral Systems, Albany, USA). The stimuli were projected via a mirror onto a screen, which was directly in the participant’s line of sight. The subject was equipped with a button which she was instructed to activate after any trial on which stuttering or blocking occurred.

2.3. Data acquisition

Brain activity was recorded with a whole-head MEG system (Model PQ1160R-N2, KIT, Kanazawa, Japan) consisting of 160 coaxial first-order gradiometers with a 50 mm baseline (Kado et al., 1999; Uehara et al., 2003). Prior to MEG measurements, five marker coils were placed on the participant’s head and their positions and the participant’s head shape were measured with a pen digitizer (Polhemus Fastrack, Colchester, VT). Head position was measured by energizing the marker coils in the MEG dewar immediately before and after the recording session. MEG was sampled at 1 kHz and band-pass filtered between 0.03 and 200 Hz.

A T1-weighted, structural MRI scan was obtained in a separate session using a 3T Siemens Verio scanner at Macquarie University Hospital, Marsfield, NSW, Australia. Scans were 1 mm isotropic.

MEG signals were bandpass filtered between 1 and 45 Hz. Epochs of 200 ms duration (1000 ms preceding and 1000 ms following the onset of the Go signal) were sorted into those where a response was executed (“successful vocalization”) and those where there was no response recorded and the subject indicated that blocking had occurred (“unsuccessful vocalization”). The epochs thus categorized were analyzed using SPM8 (Ashburner et al., 2009). Artefacts including blinks and eye-movements were removed using the artefact rejection tool implemented in SPM8. A total of 98 successful vocalizations and 134 unsuccessful vocalizations were recorded. Data were averaged and a 2D topographical representation of the evoked field for each sample of the time dimension across the epoch of interest was created for each of the 2000 samples between −1000 and 1000 ms around the stimulus onset. For display purposes these images were cropped to show between −200 and 800 ms around the stimulus onset (Fig. 1). The averaged event-related fields (ERFs) were visually examined and then passed forward to the inversion analysis.

2.4. Source space analysis

The MEG coordinate system was transformed into the Montreal Neurological Institute (MNI) coordinate system. A canonical cortical mesh derived from the MNI template was warped, in a nonlinear manner, to match the participant’s structural