The lack of focused anticipation of verbal information in stutterers: a magnetoencephalographic study

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The motivation of this work was to investigate stuttering—a disorder of speech motor control—in the light of preparatory neural activity of voluntary movements related to speech. To this end, brain activity was recorded with a whole cortex magnetoencephalograph (MEG) in developmental stutterers and nonstutterers while three different tasks of single-word reading were performed. Visually presented words had to be silently read immediately after word presentation (condition 1), spoken aloud immediately after word presentation (condition 2), or spoken aloud after a delay of 1.3 s as indicated by a second visual stimulus (condition 3).

Condition 2 clearly showed marked neurophysiological differences between stutterers and nonstutterers. Only nonstutterers showed clear neural activity before speech onset, which is interpreted as being linked to visual word presentation and to reflect focused verbal anticipation. This prespeech activity might reflect the “Bereitschaftsfeld2” (BF2) that is the later component of the “Bereitschaftsfeld”, a well-known preparatory activity described for many other voluntary movements. Our results strongly link the lack of such preparatory brain activity at the single-word level to the disability of fluent speech in stutterers. The present results strongly support the notion that stuttering is related to impaired focused attention or anticipation.

Keywords: Stuttering; Speech; Magnetoencephalograph

Introduction

Stuttering is a disorder of speech motor control (Van Riper, 1971). It is associated with involuntary repetitions, lengthened sounds, or arrests of sounds and usually prominent in emotionally and syntactically demanding speech. Possible causes for this disorder are currently under heavy debate. For example, anatomic anomalies within perisylvian speech-language areas (Foundas et al., 2001) and disconnections immediately below the laryngeal and tongue representation in the left sensorimotor cortex (Sommer et al., 2002) related to stutterers were described. Sommer et al. (2002) used diffusion tensor imaging (DTI) to detect fine details in the brain’s white matter and found that nerve fibers near by the rolandic operculum were 30% less tightly packed in stutterers than nonstutterers representing structural correlates of stuttering. Abnormal patterns of hemispheric dominance in stutterers like greater right hemisphere involvement in speech production than fluent speakers (De Nil et al., 2000; Travis, 1978) or decreased activity in the auditory area of the right hemisphere during increased stuttering (Salmelin et al., 1998) have been suggested to reflect functional causes. In addition, Fox et al. (2000) found increased activation in the right premotor regions and the nondominant left cerebellum related to increased stuttering, and Braun et al. (1997) conducted a PET study and found significant blood flow increases in the putamen, the ventral thalamus, and the inferior anterior cingulate within the left hemisphere in relation to increased stuttering.

In a recent study, Salmelin et al. (2000) used the magnetoencephalograph (MEG) to contribute to the understanding of developmental stuttering. They conducted an experiment focusing on delayed reading. Words were presented for 300 ms followed by a blank interval of 500 ms. After that, they presented a question mark for 2 s requiring the subject to read the prior presented word aloud. In other words, this experiment represents a classical contingent negative variation (CNV; Walter, 1964) paradigm with a warning stimulus (word) and an imperative stimulus (question mark). Fluent speakers demonstrated sequential brain activity related to articulatory programming and motor preparation, whereas in stutterers, a reversed activity pattern was found. The authors interpreted these results as indicating that stutterers initiated motor programs before preparation of the articulatory code. These findings occurred within the first 400 ms after word onset. Later during speech production, the right motor or premotor cortex showed consistent evoked activation in fluent speakers but was found silent in stutterers. They concluded that a network including the left inferior frontal cortex and the right motor or premotor cortex was likely to be relevant in merging linguistic and affective prosody with articulation during fluent speech appearing to be partly dysfunctional in developmental stutterers (Salmelin et al., 2000; see also Kent, 1984).
In summary, possible causes for stuttering are related to auditory processing deficits, lateralization phenomena, anatomical disconnections, or affected motor programming activity. Our attention has been directed toward the idea that affected motor programming activity represents a cause for developmental stuttering. This idea has been linked to the following history. Kornhuber and Deecke (1965) found brain activity before voluntary finger movement that became the well-known “Bereitschaftspotential” (BP). This pioneer work has triggered countless studies, involving all kinds of voluntary movements, ranging from unilateral finger and hand movements (Deecke et al., 1969, 1976), toe movements (Boschert et al., 1983; Deecke et al., 1983), eye movements (Becker et al., 1972), and also speech utterances (Grozinger et al., 1980), which are all preceded by a bilateral BP. Deecke et al. (1986) described a bilateral BP starting already 2 s before the onset of speaking, which became significantly later-

Fig. 1. Grand averaged curves and MEG maps for stutterers and nonstutterers. Curves and maps for all conditions are separately displayed. Maps were created at 52 ms after word onset. Note that only in condition 2 in nonstutterers a well pronounced activity before lip movement onset occurred (for lip movement onset, see Fig. 3).
alized toward the left hemisphere during the last 100–200 ms of
the preparation period. Deecke et al. (1986) reported that their data
are compatible with the view of an early bihemispheric motor
preparation for speech followed by a late left hemisphere prepon-
derance as the final common pathway.

Prescott (1988) conducted a study aiming at a description of
event-related potential indices of speech motor programming in
stutterers and nonstutterers. At that time, he used a contingent
electrophysiological variation (CNV; Walter, 1964) experimental design,
similar to the one used by Salmelin et al. (2000), to determine
electrophysiological differences between these two groups. A word
was first presented as a warning stimulus, and 4 s later, an
imperative stimulus (a tone) was presented as a signal to speak
aloud the respective word. He found potential differences before
speaking suggesting that stutterers have difficulty in setting up the
parameters of speaking rather than in ongoing programmed con-
trol. To date, only a few modern brain imaging studies have been
conducted to test the hypothesis that a cause of developmental
stuttering is a premotor programming dysfunction.

Various recent published reports discuss possible causes of
devolutional stuttering (e.g., Perkins, 2001; Rosenfield and
Viswanath, 2002) that made us believe that modern approaches
are useful, and any new effort that helps to augment the under-
standing is absolutely welcome.

Since the MEG has been proved to be highly appropriate for
measuring brain activity related to motor pre programming (e.g.,
Deecke et al., 1982; Erdler et al., 2000; Lang et al., 1991), word
processing (e.g., Walla et al., 2001a,b), and even related to
stuttering (e.g., Salmelin et al., 2000), we decided to use this
method for investigating brain activity before the onset of speech
in developmental stutterers focusing on a condition requiring
stutterers and nonstutterers to immediately speak aloud words after
visual word presentation. We designed an experiment using visual
single-word presentations including three different kinds of reading

### Table 1
(a) Raw data: P values related to group*sens interactions for every
condition and every single time interval, (b) normalized data: P values
related to group*sens interactions for every single condition and every
single time interval

<table>
<thead>
<tr>
<th>Interval in ms</th>
<th>−200 to −100</th>
<th>−150 to −50</th>
<th>−100 to −50</th>
<th>0 to 50</th>
<th>50 to 100</th>
</tr>
</thead>
<tbody>
<tr>
<td>a Condition 1</td>
<td>0.281</td>
<td>0.340</td>
<td>0.373</td>
<td>0.233</td>
<td>0.182</td>
</tr>
<tr>
<td>Condition 2</td>
<td>0.051</td>
<td>0.024</td>
<td>0.018</td>
<td>0.002</td>
<td>0.340</td>
</tr>
<tr>
<td>Condition 3</td>
<td>0.340</td>
<td>0.066</td>
<td>0.094</td>
<td>0.340</td>
<td>0.273</td>
</tr>
<tr>
<td>b Condition 1</td>
<td>0.204</td>
<td>0.306</td>
<td>0.233</td>
<td>0.287</td>
<td>0.353</td>
</tr>
<tr>
<td>Condition 2</td>
<td>0.062</td>
<td>0.066</td>
<td>0.133</td>
<td>0.036</td>
<td>0.047</td>
</tr>
<tr>
<td>Condition 3</td>
<td>0.268</td>
<td>0.115</td>
<td>0.138</td>
<td>0.314</td>
<td>0.550</td>
</tr>
</tbody>
</table>

Significant P values are bold.

Distribution of significant differences between condition 1 (instant reading) and
condition 2 (instant speaking) for stutterers and non stutterers

Raw data

![Non Stutterers Raw Data](image1)

![Stutterers Raw Data](image2)

Normalised data

![Non Stutterers Normalised Data](image3)

![Stutterers Normalised Data](image4)

Fig. 2. Distribution of significant differences between conditions 1 and 2 as calculated with t tests at every single sensor location for stutterers and nonstutterers (raw data and normalized data). Note that the existence of significant differences using the normalized data strongly supports the idea of functional differences between the two respective conditions in nonstutterers that are hardly evident in stutterers.
instructions. We were thus able to compare different complexity levels of reading with instant reading directly related to word onset representing the most complex task.

Methods

Participants

Eight stutterers recruited from the general hospital in Vienna (AKH, Abteilung für Phoniatrie and Logopädie) and eight age-matched nonstutterers were investigated in the present study. They were all right-handed as assessed with a modified version of the Edinburgh Inventory. They had normal or corrected to normal vision (contact lenses). Stutterers were all under speech therapy and defined as in the range between moderate and severe as it was assessed by a speech pathologist’s judgement. The mean age of stutterers was 33.1 years (SD = 18.1) and the mean age of nonstutterers was 34 years (SD = 17.7). As calculated by a one-way ANOVA, both means of age did not differ confirming the reliability of a group comparison (P = 0.923; F = 0.010).

Procedure

Within a magnetically shielded room participants were seated on a comfortable chair and viewed a screen in front of them onto which words were visually presented (distance from eyes to screen was around 1.70 m and the visual angle for words was between 1.5° and 3.6°). Each word appeared for 300 ms with an interstimulus interval of 2.5 s. Before the presentation of each word, a plus (+) was shown as a fixation point. To avoid eye artifacts, participants were asked to blink only during the presentation of the plus and not during and shortly after word presentation. In total, 222 German nouns (three to nine letters; matched for everyday occurrence, Walla, 1998) were shown during one experiment, which consisted of three sessions; each session included 74 words. During one session, participants were instructed to silently read all presented words immediately at presentation. This session is called “instant reading condition” (condition 1). In another session, they were instructed to speak aloud all presented words immediately after presentation. This session is called “instant speaking condition” (condition 2). In the last session, they were instructed to wait for a small white circle to be presented 1300 ms after word presentation and speak out aloud the respective word as soon as this circle appears. This session is called “delayed speaking condition” (condition 3). Word lists and the order of reading conditions were counterbalanced between participants.

For measuring the speaking onset, three electrodes were attached around the mouth to monitor lip movements by recording electromyographic (EMG) activity of the orbicularis oris muscle.

Recordings

MEG measurements were recorded with a 143-channel whole-head system manufactured by CTF Systems Inc. (Canada). The sampling rate was 250/s and recordings were filtered online with a band pass from 0.25 to 80 Hz. An offline band pass filter from 0.5 to 30 Hz was applied. Usually, slow-wave investigations avoiding any high-pass filtering are made to describe premotor-related activity. To investigate slow magnetic field changes by using no high-pass filtering, it is necessary to run the experiments at night times. Since we were not able to ask our participants to come at night hours (some were children) in addition to the fact that cognitive tasks like word reading are normally daytime activities, we had to introduce high-pass filtering. As a consequence, any early slow-wave activity related to the supplementary motor area (SMA) (see Erdler et al., 2000) is missing in our data. The remaining later activity shortly before movement onset (Erdler et al., 2000) is described in the present study. Average event-related fields (ERFs) were calculated for each participant and across all eight participants of both stutterers and nonstutterers for each condition. Averaging was done with respect to word presentation. Intra-individual head positions were not changed between experimental sessions and inter-individual differences were kept as small as possible. Magnetic field maps were created to visualize the magnetic field distributions.

To measure the lip movement onset, EMG activity was recorded (orbicularis oris muscle) using the electroencephalography (EEG) amplifier by CTF Systems, attached to the MEG system for simultaneous use.

Statistics

The mean amplitudes of 100 ms intervals (overlapping for 50 ms) covering the time range from −200 ms prior stimulus onset to 100 ms after stimulus onset were determined for each participant, each condition and each sensor. For an additional analysis, these mean amplitudes were also normalized according to McCarthy and Wood (1985) to diminish any amplitude differences between participants for a group comparison between stutterers and nonstutterers. For each condition, two-way ANOVAs using the mean amplitudes as dependent variables were applied to both the raw data and the normalized data. The factors “group” (stutterers and nonstutterers) and “stimulus condition” (condition 1, 2, 3) were treated as fixed effects. Condition 3 was included to control for the most complex task.

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**Fig. 3.** Electromyogram (EMG) of the orbicularis oris muscle to visualize the approximate onset of lip movement in stutterers and nonstutterers related to condition 2.
Results

At first, it has to be mentioned that both stutterers and nonstutterers had no problems speaking aloud the presented words, neither in condition 2 nor in condition 3. The fact that stutterers too had no problems is not surprising because single-word reading is known to be mostly unaffected. In principal, the grand averages for each condition across all participants within both stutterers and nonstutterers revealed a typical pattern of magnetic activity related to word information processing as has been demonstrated in previous MEG studies (e.g., Walla et al., 2001a,b). A series of activity components including exogenous brain activity reflecting principal visual information processing and endogenous brain activity reflecting cognitive information processing can be observed (Fig. 1). Moreover, Fig. 1 strikingly shows the existence of a particular brain activity starting before word onset in condition 2 that is weaker in condition 3 and missing in condition 1.

Statistical analysis underlined the significance of this particular brain activity starting at about −200 ms before word onset and lasting until about 50 ms after word onset in condition 2 in controls. ANOVAs applied to raw and normalized data revealed significant group*sens interactions from about 200 ms before word onset until about 50 ms after word onset (for P values see Table 1). The fact that these interactions were also significant using the normalized data (from about −50 ms to 100 ms) is interpreted as reflecting functional differences between stutterers and nonstutterers related to condition 2. In condition 1, no such significant interactions occurred at all, whereas in condition 3 between around −150 ms to word onset (0 ms), a certain trend toward significant group*sens interactions occurred.

In addition, t tests were calculated for every single sensor location to compare conditions 1 and 2 for stutterers and nonstutterers. The distribution of significant differences in nonstutterers strongly resembles the magnetic field distribution of condition 2 alone (raw data and normalized data) (Fig. 2). This means that condition 2 is associated with brain activity, especially before word onset, which is missing in condition 1 in nonstutterers. In stutterers, such differences between conditions 1 and 2 did not occur.

Fig. 3 demonstrates the onset of lip movement in condition 2 for stutterers and nonstutterers. The average lip movement onset of stutterers was at about 270 ms after word presentation whereas the average lip movement onset of nonstutterers was at about 250 ms after word onset. Since it has been shown that reaction times in stutterers are slower than in nonstutterers, this slight shift if at all reliable is not surprising (Starkweather et al., 1976; Watson and Alfonso, 1983).

According to the distinct distribution of magnetic fields related to condition 2 in nonstutterers, a two-dipole model was used to approximately localize possible sources underlying the respective brain activity. As can be seen in Fig. 4, these localized dipoles reflect bilateral activities with left hemisphere dominance supporting the idea of motor cortex or close to motor cortex activity as visualized by average brain activity across all nonstutterers.

Discussion

Using the MEG, we find brain activity related to the onset of word presentation under the condition of immediate speaking in nonstutterers that is compatible with the notion of a “Bereitschaftsfeld2 (BF2)” as it was described by Erdler et al. (2000) (Fig. 1). The main finding of the present study is that this activity is absent in developmental stutterers in case of immediate speaking even in the absence of stuttering. Deecke et al. (1986) demonstrated the existence of a “BP” before the onset of speaking. In principal, a common bilateral preparatory mechanism for each movement or action that is voluntarily initiated can be expected. Deecke et al. (1986) found a significant lateralization to the left hemisphere about 100 ms before the onset of speech. This activity was interpreted as being closely connected to the final motor mechanisms of speech. McAdam and Whitaker (1971) found greater EEG amplitudes over the left speech motor area than over the respective right hemispheric area before multisyllable words. In
According to these studies, our present data demonstrate a left hemisphere dominance at or close to motor cortex related to word onset in condition 2 (immediate speaking) and almost significant in condition 3 (delayed speaking) of our experiment as seen in Figs. 2 and 4, and might therefore also be related to final motor mechanisms of speech. However, the situation could be a bit more complex than originally thought.

As mentioned in the Introduction, Salmelin et al. (2000) already used the MEG to contribute to the understanding of developmental stuttering. They conducted an experiment focusing on delayed reading. Their experiment represents a classical contingent negative variation (CNV; Walter, 1964) paradigm with a warning stimulus (word) and an imperative stimulus (question mark). Earlier, Prescott (1988) also conducted a contingent negative variation (CNV) experiment using the electroencephalography (EEG) investigating brain activity before spoken words in stutterers and nonstutterers. In this study too, visually presented words were the warning stimuli whereas a tone presented to both ears represented the signal to speak. Prescott (1988) already emphasized the robust nature of EEG effects related to speech programming. He compared both averaging procedures, averages locked to the presentation of words, and averages locked to speech onset. The effects found in this study were present in both types of averages. Therefore, Prescott already pointed to the fact that brain activity related to visual word presentation includes functions that actually belong to the speech motor system. According to this idea, we were interested in brain activity related to the onset of visually presented words by providing three different conditions, two of them including speaking of visually presented words. MEG was used to describe the associated dynamics of brain activity. Speech motor control as a system is suggested to include several functions such as the planning and preparation of movements (motor programming) and the execution of movement plans to result in actual muscle contraction to produce respective articulation.

Under experimental conditions such as in conditions 2 and 3 within the present study, the speech motor system in principal is set as “be prepared to go” at any time. This is so because study participants know that the task in both conditions is to speak out loud visually presented words before the start of each experimental run. This kind of activation would be expected as to be slow-wave activity within the supplementary motor area (SMA). As described in the method section, the band pass filter that we used for offline filtering cut off the respective low frequencies that usually show SMA activity. The more detailed motor programming related to speech includes motor cortex activation at areas where the muscles that are to be contracted are represented. This kind of brain activity is of a higher frequency than SMA activity. Such speech motor programming is always linked to the respective verbal information that has to be articulated. Therefore, an important step during speech motor programming certainly is the “focused verbal anticipation”. In case of reading, this verbal information comes from more posterior brain areas, including the well-known “Wernicke-area” that gets essential input from the visual system at least during visual presentation of words.

In the present study, two conditions related to speaking of visually presented words were provided. Compared to a silent reading condition (condition 1), participants had to speak out loud visually presented words immediately after word presentation (condition 2) or 1.3 s after word presentation (delayed speaking, condition 3).

Besides the externally triggered function related to the actual beginning of motor action (immediate or delayed) that is called motor execution (when to speak?), the main function is related to “focused verbal anticipation” (what to speak?). As soon as a word appears on the screen, the function of “focused verbal anticipation” gets all necessary input it waited for to execute speaking. Therefore, brain activity related to “focused verbal anticipation” is expected to happen before visual word presentation and somehow related to it. This is exactly what we interpret our neurophysiological finding from condition 2 in controls to reflect. Interestingly, condition 3 in controls demonstrates a quite similar activity distribution within the same time range just not as pronounced as in condition 2. Statistical analysis revealed close to significance results that obviously can be interpreted as a certain trend in condition 3 as well (see Table 1). The respective magnetic field distribution as well as the localized dipoles can be seen as to reflect motor cortex (or close to motor cortex) activation associated to visual word presentation within a speaking task. Therefore, we suggest that motor cortex (or close to motor cortex) activation before visual word presentation is related to “focused verbal anticipation”. We further interpret that motor programming itself is at least partly included in this process.

On the other hand, the function of speech production or speech motor execution is related to the actual speech onset and something different. In condition 2, it overlays the function of “focused verbal anticipation”. In condition 3, both processes are separated, but unfortunately, we did not intend to analyze our data with respect to speech onset and therefore we did not take care of artifact control at later latencies around speech onset in the delayed speaking condition.

Our findings provide evidence that premotor programming (motor cortex or maybe Broca’s area) related to speech, includes focused verbal anticipation, and second, we suggest that focused verbal anticipation is the crucial function that is affected in developmental stutterers.

Among various theories of stuttering, our findings therefore clearly favor dysfunctions related to “focused verbal anticipation”, which is suggested to be a function within the speech motor system. We pinpoint this dysfunction to the missing of a preparatory activity before speech onset, which is directly related to the detailed motor program and relate our finding to the BF2 as it was described by Erdler et al. (2000). Our idea is that the speech motor system anticipates verbal information to come in order to be translated into various distinct motor events to produce speaking. Within a study such as the present investigation, this activity is linked to word presentation.

In stutterers, even though single-word reading was not affected, that is, reading with almost no stuttering, this circumstance might be a reasonable cause for impaired fluent speech in stutterers. The fact that single-word reading was not impaired, although no or only weak motor preparation (focused verbal anticipation) was found in stutterers, might be due to other distinct findings. In various studies, the amplitude of the BP has been found to reflect the voluntary movement to be performed with respect to speed, force, and complexity (e.g., Hink et al., 1983; Kristeva, 1984; Prescott, 1986). It can therefore be assumed that the lack of such activity has a strong negative effect on fluent speech, which certainly represents a complex task, whereas single-word reading is much easier to accomplish and does not necessarily need the same amount of preparation.
Conclusion

We found evidence that speaking aloud visually presented words is associated with certain brain activity at or close to the motor cortex on the left hemisphere in nonstutterers but not in developmental stutterers. This brain activity is interpreted as reflecting focused verbal anticipation. Although stutterers were not impaired in speaking aloud the visually presented single words, the lack of any such activity is interpreted as causing dysfluent speech in stutterers in general. This interpretation is because fluent speech is more complex than speaking aloud single words. The present results can be seen as supporting the idea of stuttering to be related to impaired focused attention or anticipation with respect to verbal information processing.

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References


