

Neural Dynamics of the Intention to Speak

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When we talk we communicate our intentions. Although the origin of intentional action is debated in cognitive neuroscience, the question of how the brain generates the intention in speech remains still open. Using magnetoencephalography, we investigated the cortical dynamics engaged when healthy subjects attended to either their intention to speak or their actual speech. We found that activity in the right and left parietal cortex increased before subjects became aware of intending to speak. Within the time window of parietal activation, we also observed a transient left frontal activity in Broca's area, a crucial region for inner speech. During attention to speech, neural activity was detected in left prefrontal and temporal areas and in the temporoparietal junction. In agreement with previous results, our findings suggest that the parietal cortex plays a multimodal role in monitoring intentional mechanisms in both action and language. The coactivation of parietal regions and Broca's area may constitute the cortical circuit specific for controlling intentional processes during speech.

Keywords: Broca's area, magnetoencephalography, motor intention, parietal cortex, speech

Introduction

Speech is the most sophisticated mean we use to convey our thoughts. When we speak we can assert, request, or refuse something: In all these cases, we perform intentional communicative actions. The problem of intention in action (Searle 1983) has recently attracted great attention in neuroscience. No study has looked specifically at monitoring of intention to act with respect to speech. This issue can be formulated as follows: how and when does the decision to speak become a conscious intention, that is, a "wanting to talk" and what brain areas monitor the early emergence of such an intention?

Studies in normal volunteers focusing on upper limb movement have shown that movement intention and awareness are anticipated with respect to movement execution. Hence, subjects reliably report the experience of wanting to move ~300 ms before movement onset (Libet et al. 1983). Interestingly, this conscious experience is preceded by a neural signal, the readiness potential (RP), generated in the motor areas and classically found during preparation of hand gestures and/or orofacial movements (Libet et al. 1983; Wohlert et al. 1993; Haggard and Eimer 1999; Haggard et al. 2002; Sirigu et al. 2004).

Neuropsychological results have demonstrated that damage to a specific region of the brain, the parietal cortex, alters these early stages of conscious intention and motor awareness during self-initiated actions. Patients with parietal lesions can report the exact moment when they started to move their hand but not the moment when they first became aware of their

intention to move. Furthermore, contrary to normal subjects they do not show the associated RP (Sirigu et al. 2004). These results indicate that damage to the parietal lobe leads to an inability to monitor the early stages of intention and action awareness. These findings suggest that the parietal cortex holds neural mechanisms important for attention to intention during movement planning (Sirigu et al. 2004).

A key question is whether the involvement of parietal cortex in intentional processes generalizes to other motor behaviors and in particular to speech. Similarly to arm and hand movements, speaking is also accomplished through motor acts. It is well established that there is a close link between language and the motor system (Pulvermüller 2005). Motor cortex responses to speech are sensitive to the specific articulators of speech sounds (e.g., lips vs. tongue; Pulvermüller et al. 2006), and it has recently been suggested that the motor regions play a crucial role in modulating conversational speech during turn taking (Scott et al. 2009).

Neuropsychological results have also indicated that the parietal lobe damage impairs both production of gestures related to tools and speech planning (Rosenbeck et al. 1978; Damasio and Damasio 1992; Grant et al. 1999; Cubelli et al. 2000; Haaland et al. 2000; Daprati and Sirigu 2006).

A recent study has shown that direct stimulation of the inferior parietal cortex during brain surgery in awake patients triggers the sensation of have intended to talk or the illusion to have moved the lips and have said something, thus demonstrating that parietal regions have a mandatory role for the control of intention in language (Desmurget et al. 2009).

Furthermore, recent diffusion tensor magnetic resonance imaging studies in humans have shown an indirect pathway in the lateral sector of the superior longitudinal fasciculus. Two segments within this pathway originating in the parietal lobe project toward regions important for language processing: The posterior segment ends up in the inferior temporal region while the anterior in the inferior frontal gyrus (Catani et al. 2005). It is possible to speculate that prior intentions elaborated in prefrontal areas are sent via this corticocortical connection to the parietal cortex to be translated as intentions for a potential action or movement. The selective activation of this circuit may further enable the parietal cortex to specifically monitor signals related to the intention to talk and the planning of speech acts.

To investigate the brain network involved in the intention to speak, we used a paradigm first proposed by Libet et al. (1983) and adapted from Sirigu et al. (2004). Twelve right-handed healthy volunteers (mean age: 24.5 years) were asked to pronounce the word "demain" ("tomorrow") at a time of their own choosing, following a trial start cue. While performing this simple task, subjects were instructed, in separate blocks of

trials, to focus their attention on either the actual onset of the word pronunciation or the internal decision to pronounce it.

Judgments about the time of each event were performed in the following way: participants looked at the single hand of a clock that started to move at the beginning of each trial and stopped at a random time following speech onset (Fig. 1). Subjects reported the position of the clock's hand either at the time they started speaking (S-judgment) or at the time they first became aware of their intention to speak (I-judgment). In the Intention condition, the experimenter instructed the subjects as follows: "Note the position of the clock's hand at the time when you feel the desire to speak but you have not start speaking yet." At each trial, subjects were told to feel free to speak whenever they wanted but not before the clock's hand had completed its first turn.

We used magnetoencephalography (MEG) in order to track the spatiotemporal neural dynamics related to speech and to the intention of speaking (see Materials and Methods).

Materials and Methods

Participants

Sixteen healthy participants were included into the protocol. All subjects were French native speakers, right-handed according to the Edinburgh handedness test (Oldfield 1971), and reported no history of neurological or psychiatric disorders. A written informed consent was obtained from each participant. Subjects' recordings were screened to eliminate those with frequent blinking or signal artifacts (e.g., due to dental work). Four subjects have been rejected because of artifacts. The remaining 12 subjects have been included for analysis.

Behavioral Task

Subjects sat in front of a screen inside the magnetically shielded room (40 cm from the screen). A calibrated clock face (radius: 2.2 cm; marked in steps of 5 units from 0 to 60 like a usual clock) was visually projected on the center of the screen (Fig. 1).

At the beginning of each trial, a red clock hand started to turn clockwise (start spin) from a random location at the speed of 2560 ms per cycle. Subjects were instructed to pronounce the one-word-like utterance "demain" (tomorrow) at a time of their own choice after having waited a first complete cycle. They were required to execute the task as spontaneously as they could, avoiding to adopt any strategy (e.g., choosing the position of the hand clock before speaking and use it to trigger their speech act). In one block of trials, subjects were instructed to attend to their intention to speak and to report the location of the clock hand at the moment of their internal decision to speak ("Intention" condition). In a separate block of trials, they were asked to attend to the actual speech onset and to report the location of the clock hand when they started to speak ("Speech" condition).

For each condition, blocks of 100 trials were run, each presented in a random order. In a pretest session, subjects were trained in the MEG with 100 repetitions of both Intention and Speech conditions. Stimuli

were presented using the Presentation software (neurobehavioral system, <http://www.neurobs.com/>).

Data Acquisition

MEG Recording

The continuous raw MEG signals (sampled at 1200 Hz) were recorded using a high-density whole-head system (OMEGA; CTF Systems, VSM Medtech, Vancouver, BC, Canada), provided with 275 axial gradiometer channels and 29 dedicated reference channels for environmental noise cancellation. At the beginning of each block, subject's head position relative to the MEG sensors was measured using coils placed at 3 fiducial points (nasion, left and right preauricular points). Head movements did not exceed 1.25 cm between blocks.

Speech Data

Subject's verbal responses were recorded through a MEG-compatible microphone and recording software (Cool Edit Pro).

Behavioral Data

During each MEG session, participants' verbal time reports were constantly monitored and written by the experimenter. Trials showing uncertainty or failure in reporting the required time were excluded from analysis. Subjects were visually monitored on a closed circuit TV system.

Data Analysis

Behavioral Data

Participants' temporal judgments were calculated by subtracting the time of the actual speech onset from the time at which they reported 1) to have first intended to speak (Intention condition) and 2) to have started speaking (Speech condition). Negative values indicated that subjects' estimate preceded the speech onset, while positive values indicated that it followed the observed event. Latencies of subjects' overt speech production were also calculated, by subtracting the time of speech onset from the time at which the first clock cycle ended up. Speech signals have been amplified and analyzed using Praat software (<http://www.praat.org>). Trials with no speech responses, corrupted speech, or artifacts (e.g., deglutition and cough) were rejected. Speech onset times were identified by visual inspection of the speech signal.

MEG Data

MEG signals were digitally filtered off-line with a bandwidth of 0.2–60 Hz and decimated down to 300 Hz. Signals were analyzed at 2 levels, namely the magnetic field distribution measured at the sensor surface (sensor level) and the estimated cortical current sources that underlie the recorded magnetic fields (source level).

Sensor level. In a first analysis, the electrophysiological effects of Intention were assessed by comparing the fields in the period preceding the speech onset in the 2 conditions (Intention vs. Speech) using sample-by-sample *t*-tests for paired data across all subjects. Differences were considered significant at $P < 0.05$ for at least 15 consecutive time samples (Blair and Karniski 1993; Thorpe et al. 1996) for at least 4 neighboring sensors. This method can determine precisely the time range and the scalp regions of the difference between the 2

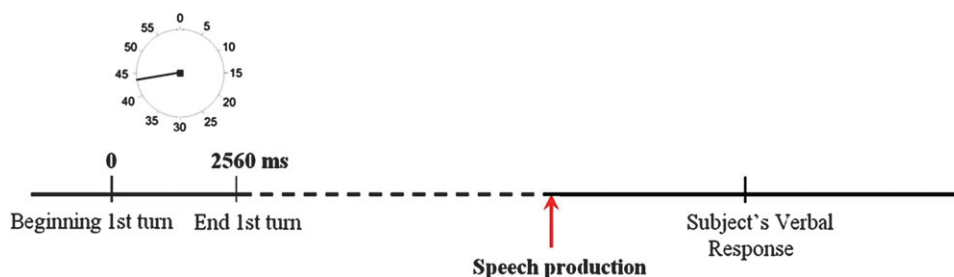


Figure 1. Example of a trial. The discontinuous line indicates the variable time period from the end of the first clock turn and the beginning of speech production.

conditions. The topography of the effect was illustrated in MEG field interpolation maps and Student's *t*-test maps.

Source level. In a second analysis, the spatiotemporal dynamics of cortical sources underlying the measured magnetic field distributions were determined for both the Intention and the Speech conditions. We imaged the foci of activations that were time locked to the speech onset using minimum-*l*-norm current estimates implemented into the Brainstorm software (<http://neuroimage.usc.edu/brainstorm/>). The method calculates the source currents of smallest amplitude by applying minimum norm (MN) priors on source amplitudes. This approach was adopted because it does not require prior assumptions about source location and number, contrary to multiple dipole fit methods, and provides detailed information about the time course and the spatial location of brain activity. MN estimates were applied to the averaged signals (0.2–20 Hz) of individual subjects for each condition in a time window from –2 s before the speech onset time to +0.1 after speech onset. Standard Tikhonov regularization (10%) was applied for noise reduction. MN current estimates were computed for each participant individually and for consecutive points in time within a source space consisting of about 10 774 vertex points of a template cortex mesh.

To determine the neurophysiological effect specific to the Intention condition, we compared at each vertex the MN estimates of source amplitudes in the 2 examined conditions using sample-by-sample paired *t*-tests. *P* values have been corrected using Bonferroni correction: Vertex were considered significantly different at time *t* if $P(\text{vertex}) < 0.05/\text{number of vertices}$.

Results

Behavioral Data

Participants reported to have started speaking (S-judgment) 54 ms earlier than the actual speech onset (± 78 ms standard deviation), and they estimated their intention to speak (I-judgment) 352 ms before actual speech onset (± 124 ms). Statistical comparison revealed that the 2 temporal judgments differed significantly, $P = 0.0002$ (2-tailed paired *t*-test). To ascertain that the specific temporal judgment task of the Intention and the Speech conditions did not affect self-generation of speech act, speech onset latencies were examined in each condition. Average speech onset began 3800 ms (± 658 ms) and 3605 ms (± 366 ms) following the end of the first clock turn in the Intention and the Speech conditions, respectively. These values did not differ significantly, $P = 0.26$ (2-tailed paired *t*-test). Thus, speech onset occurred at about the same time in both conditions, irrespective of the temporal judgment subjects were performing. Intersubject variability of speech production times was determined by the standard deviation averages of the speech onset latencies for the Intention (554 ± 430 ms) and the Speech condition (466 ± 237 ms). No significant difference emerged from this contrast $P = 0.2$ (2-tailed paired *t*-test).

In summary, our behavioral results show that conscious intention of wanting to speak is anticipated with respect to speech production per se. Interestingly, temporal difference of a similar magnitude between intention and movement was also reported in the context of hand gestures when subjects focused on their intention to move as compared with when they paid attention to movement execution (Libet et al. 1983; Sirigu et al. 2004; Haggard 2005, 2008).

MEG-Evoked Responses at the Sensor Level

Mean magnetic field distribution elicited by both Intention and Speech conditions exhibited specific dipolar topographies

during the preparatory phase preceding speech production. A large outward (positive) flowing field was found over the frontal and temporoparietal sensor areas on the left side of the scalp, whereas an opposite inward (negative) flowing current was spread over the temporoparietal sensor areas on the right side of the scalp. This spatial field distribution was partially common to the 2 examined conditions, both involving motor preparation and overt speech (see MEG field maps at the top of Fig. 2*a*). However, a difference was observed between the time courses of MEG responses in the 2 conditions.

The inward magnetic flow was significantly higher for the Intention judgment ($P < 0.05$, 2-tailed paired *t*-test; see contrast at the bottom of Fig. 2*a*). Such negativity emerged at the right occipitoparietal sensors during a time window from –776 to –94 ms before speech onset ($P < 0.05$).

In a further analysis, we examined the time course of negative peaks in separate groups of selected right parietal (Fig. 2*b*) and occipital sensors (see Fig. 2*c*). In the parietal group of sensors, we found that the negativity was significantly stronger in the Intention condition ($P < 0.05$; 2-tailed paired *t*-test) during a time window from –776 to –390 ms before speech onset. It must be stressed that this parietal negativity arise –424 ms prior subjects' reported time of intention to speak and decreases –38 ms earlier.

A similar negativity pattern was found from a subgroup of right occipital sensors. The negative signal amplitudes differed significantly between conditions (Intention vs. Speech) during a time window from –776 to –93 ms (before speech onset; $P < 0.05$; 2-tailed paired *t*-test).

These first set of results show that attending the intention to speak is preceded by an activity in the parietal and the occipital sensors. Although activity in these 2 regions begins jointly their time course diverged. Hence, the signal generated in parietal cortex is transient, decaying just before the time of the reported intention, whereas the occipital negativity is sustained and extends up to when speech begins.

MEG Sources of Brain Activity

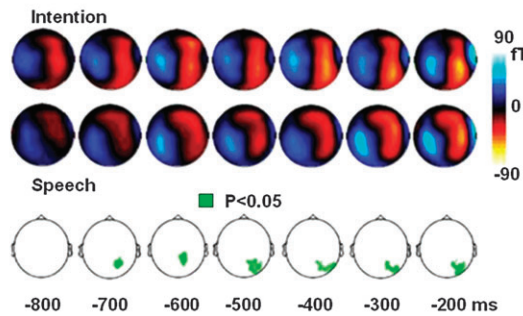
Distributed source localization by MN current estimates confirmed the MEG-evoked field analysis and also revealed a complex spatiotemporal dynamics of neural events distinct for each condition.

Activity Related to Intention Condition

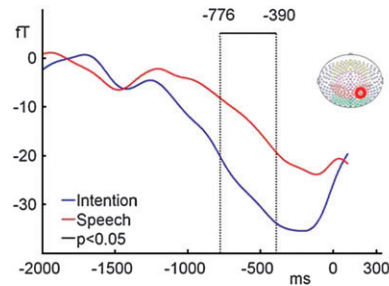
When subjects were attending to their intention to speak, we found a local activity in the superior right parietal cortex (BA 7; Intention vs. Speech condition, $P < 0.05$) occurring from –883 to –730 ms before actual speech (Fig. 3*a*). This parietal activity was then followed by an increase of the MEG signal in the left inferior frontal gyrus or Broca's area (BA 45) for about 70 ms (from –740 to –670 ms). Following, from about –693 to –530 ms (before speech onset), the early right parietal activation spread throughout the right superior parietal lobe to include the precuneus (BA 5), the right intraparietal sulcus to shift then shortly in the left inferior and superior parietal regions. Within the same time window (from –670 to –550 ms) and following the parietal activity, a right prefrontal (BA 10, 11, 46) and orbitofrontal cortex (BA 10, 11; from –730 to –650 ms before speech onset) activity occurred.

Increased activity was also found within the right primary and secondary visual cortex (BA 17, 18) for about 108 ms

a. Spatio-temporal patterns of MEG field distribution



b. Right parietal MEG field



c. Right occipital MEG field

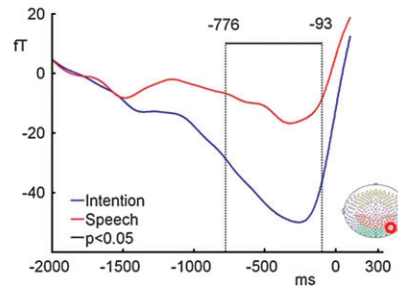


Figure 2. MEG data. (a) (top) MEG field maps of the grand average of the signal in Intention and Speech conditions from -800 to -200 ms before speech onset. A similar pattern of outgoing MEG field distribution was found on the left side of the map. Conversely, on the right side, an early ingoing magnetic field appeared over parietal sensor areas during Intention, whereas it was concentrated over the right frontal areas during Speech. (Bottom) Statistical contrast between the grand average of the signal in Intention versus Speech shows that the ingoing magnetic field was significantly higher in Intention than in Speech over the right parietal and occipital areas (sample by sample paired t -test, $P < 0.05$, at least 15 consecutive samples). (b) Averaged signal from a subgroup of selected parietal sensors. Negativity is higher in Intention (blue) than in Speech condition (red). Dotted lines indicate the time window in which the signal differed significantly over time, namely, from -776 to -390 ms before actual speech. (c) Averaged signal from a subgroup of selected occipital sensors. Negativity is higher in Intention (blue) than in Speech condition (red). Dotted lines indicate the time window in which the signal differed significantly over time, namely, from -776 to -93 ms before actual speech.

during the same time interval (from -698 to -590 ms before speech onset; see Supplementary Fig. 1).

During a subsequent interval (from -430 to -293 ms before speech) corresponding to a period when subjective time of intention was completed (as reported by subjects) activity was again found in the parietal region, this time located in the right inferior temporoparietal junction (BA 39, 21). Lastly, sources activity in the right occipital region (BA 19) and right superior temporal lobe (BA 37) exhibited a transient activity (from -440 to -370 and from -465 to -363 ms before speech onset, respectively).

This finding thus confirms that the negativity signal found in the parietal sensors, as revealed by the magnetic field analysis, takes its source very early in the parietal regions and in Broca's area followed by activation in posterior and prefrontal areas (see Supplementary Fig. 2a). More importantly, source analysis further confirms that the timing of the parietal cortex signal is closely related to that of intention to speak: it arises early and decays just before time of intention.

Activity Related to Speech Condition

We also identified cortical sources that were significantly more active in the Speech than in the Intention condition ($P < 0.05$). These included a left frontal temporal network of language areas that were activated at distinct time courses (Fig. 3b). A first earlier speech-specific activity was found in the left frontal cortex (BA 46) lasting for about 50 ms (from -740 to -670 ms), followed by activity in the left inferior temporal cortex (BA 21; from -670 to -530 ms). Later (from -320 to -160 ms) other foci

of activity were found in the left inferior temporal cortex (BA 21-22, 38). Interestingly, during the same time window, 2 selective activations were found in the lateral, portion of the motor (M1), and sensory (S1) cortex corresponding to the classical mouth area. Since this activity occurs close to speech onset, it might reflect word movement preparation or word movement rehearsal (Supplementary Fig. 3). Further sources of brain activity emerged in areas known to be involved in language processing such as the right superior temporal cortex (BA 37 and 21-22) and the left temporal parietal junction within a time interval from -215 and -150 ms to speech onset time, respectively. For the specific time course of the reported source activities see Supplementary Figure 2b.

Discussion

In our study, we asked subjects to pronounce a word after a clock's hand had completed its first turn and then to report its position when they first experienced the intention to speak or when they began speaking. Focusing attention either on the speech intention or on the act of speaking was found to produce different patterns of the neural activity in specific brain areas as measured by the MEG-evoked response and source analysis. The results corroborate our prediction that the parietal cortex plays a key role in monitoring the mechanisms related to motor intention in language, as it does for other motor actions. We further show that parietal activation was followed by increasing signals in additional cortical areas, each being activated within a specific time window throughout the task.

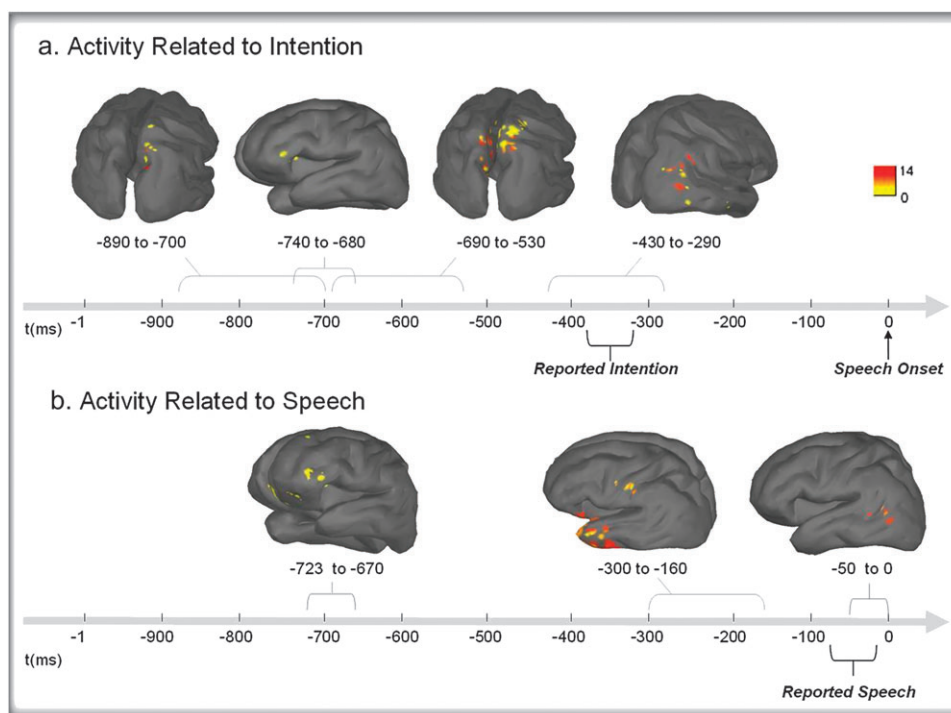


Figure 3. (a) Spatiotemporal dynamics of reconstructed sources of brain activity specific to the Intention condition. From left to right, early right parietal activity (BA 7), activity in the left inferior frontal gyrus (BA 45), bilateral parietal activity (BA 7), and right inferior parietal activity (BA 39). (b) Spatiotemporal dynamics of reconstructed sources of brain activity specific to the Speech condition. From left to right: left prefrontal activity (BA 46), left superior temporal activity (BA 21), and inferior temporal activity.

The results from MEG-evoked response showed a right parietal readiness signal when subjects focused on their intention to talk. The time course of such signal is remarkable since it occurs within a time window that immediately precedes reported subjective time of intention (from -424 to -38 ms before reported intention). This result is consistent with the hypothesis of an involvement of the parietal cortex for motor intention in speech. Jointly to the parietal activation, monitoring the intention to speak also induced an early activation (-424 ms before reported intention) in the right occipital area. Note that contrary to the transient activation found in the parietal cortex, however, the occipital negativity encompassed the window of the reported time of intention going on up to when subjects prepared to speak ($+259$ ms after reported intention and -93 ms before speech onset). Because time of intention was anticipated with respect to speech, it is reasonable to assume that in the Intention condition subjects maintained very early in time in a visual buffer a mental image of the clock's hand position. The occipital activation may be thus understood as triggered by a visual imagery process significantly early in the Intention condition compared with speech. Accordingly, this occipital activity should be viewed as being associated with (due to the early detection of the clock hand position at the time of the intention to speak) but not instrumental for processing intention in speech.

The result obtained from evoked responses analysis does not inform on the specific brain areas that generate the parietal and occipital negativity observed at the sensor level. Hence, such activity may be driven for instance by cortical sources different from the spatiotemporal distribution of the MEG fields measured at the scalp level. To address this issue, we performed a finer-grained analysis to identify the underlying sources of

these brain signals. The results showed that different sources of cortical activity contribute to the spatiotemporally distinct effects observed at the sensor level.

First of all, when we contrasted the activity found in the Intention and Speech condition, the results show a cluster of generators in the right parietal cortex where activity arose early (from -531 to -378 ms before the subjective time of reported intention, i.e., from -883 to -730 ms before actual speech) and significantly strong when subjects were focusing on wanting to speak. These foci of parietal cortex activity spread out fast from right to left inferior and superior parietal areas to decrease within the time window of reported intention (-178 ms before reported intention). Thus, both the evoked response and source results demonstrated the contribution of parietal regions in monitoring very early motor intention in speech. More important, these findings indicate that a neural signal increases in the parietal cortex before subjects are fully aware of their intention to speak. Direct support for this hypothesis comes also from a recent study performed in our group where it has been showed that direct stimulation of different parietal cortex sites causes the intention to move a specific body part (the hand, the arm, the leg, or the chest) or the intention to talk (Desmurget et al. 2009). In accordance with previous hypotheses, it may be that we become aware of our intention as a result of the increasing activity in the parietal cortex (Blakemore and Sirigu 2003; Sirigu et al. 2004; Desmurget et al. 2009).

Interestingly, source analysis also revealed that when the very first right parietal activity decays (about -378 ms before subjective time of intention and -730 ms before actual speech) a 10-ms transient (70 ms) left frontal activity in Broca's area occurs, a region this one known to be important in language

and action processing (Rizzolatti and Arbib 1998; Nishitani et al. 2004; Davis et al. 2008).

It is interesting to note that Broca's region has been associated with the control of inner speech.

Inner speech refers to behavior where subjects rehearse words silently and according to some authors it involves similar mechanisms as those involved in self-awareness (Levine et al. 1982; McGuire et al. 1993, 1996). We can speculate that when focusing on the intention to speak, self-awareness mechanisms are mandatory. Although the respective role and dynamic interplay between parietal and Broca's region in motor intention processes cannot be established here, we can propose that Broca's area is coactivated with parietal cortex "only" when intention in action is processed for the purpose of producing speech. This circuit may thus constitute the functional counterpart of the parietofrontal circuit described at the anatomical level by diffusion tensor studies (Catani et al. 2005, 2007).

The task we used in our study (word pronunciation) should have had primarily engaged left hemisphere linguistic functions. Yet, activity near the occurrence of time of intention to speak was found in both the right and the left parietal regions. Although this may be surprising, the role of right parietal region in motor and body awareness is well known (Frith et al. 2000). Awareness and failures in the control of action are associated with bilateral activation of parietal regions (Farrer and Frith 2002). Also, increase of activity in the right inferior parietal cortex (angular gyrus) is observed when subjects are required to detect a mismatch between the expected and the perceived outcome of an intended action (Farrer et al. 2008). In the language domain, several studies have stressed the function of this region for pragmatic and communicative aspects (beliefs, reading others' intention) conveyed through speech (Sherratt and Penn 1990; Surian and Siegal 2001). Our results further suggest that both the right and the left parietal cortex also monitor high-level aspects of language such as intention during speech acts.

When subjects focused their attention on speech rather than intention we found early transient activity in dorsolateral and orbitofrontal prefrontal areas. In this condition, motor preparation processes were probably highly activated since subjects were instructed to focus their attention on word pronunciation itself. Prefrontal activations may be thus directly linked to the need to inhibit the motor output from the early stage of our task (Elliott et al. 2000; Lee et al. 2001; Rubia et al. 2001, 2003).

The idea that in the speech condition subjects were focusing on movement preparation and speech rehearsal is also supported by further activity in the motor and the sensory cortex specifically involving the mouth area. Recent research has highlighted the role of these regions in motor imagery (Jeannerod 1994; Decety and Jeannerod 1995). Finally, activity was observed in left temporal and temporoparietal junction when subjects were near to pronounce the word, consistent with the role of this region in speech production (Wise et al. 2001).

In conclusion, our study has shown that a set of specific cortical areas subserves intention in speech. A key contribution is played by parietal regions that seem instrumental in triggering intentional speech mechanisms very early in time. According to our results, parietal activity increases "prior" to the intention to speak. Previous studies have recorded the RP, a neurophysiological signal linked to motor preparation and generated in the motor areas, while subjects focused on their intention to perform a hand movement. The results showed

that the RP negativity raises before subjects become aware of their will to move (Libet et al. 1983; Haggard and Eimer 1999; Sirigu et al. 2004). In the light of our results, we can speculate that the RP signal in the motor areas is driven by remote activity in the parietal cortex.

Finally, these results extend the findings reported by Sirigu et al. (2004) and Desmurget et al. (2009) that highlighted the critical role of parietal area during motor intention and reinforce the hypothesis of a multimodal role of the parietal lobe in controlling intention both in action and language.

Another contribution comes from Broca's area, where activity occurs right after the parietal one and, as proposed above, these 2 regions may represent the cortical circuit specific for controlling intentional processes related to speech.

Since we use language for communicative purposes, attending "intention to speak" may also have implicitly triggered a communicative dimension even if this was not encouraged by our task instruction. To further push this reasoning, we can speculate that the mechanisms involved in intending to speak are also called into play when we use speech to fulfill an explicit communicative purpose (e.g., answering a question). Parietal cortex and Broca's area may be at the source of this behavior.

Supplementary Material

Supplementary material can be found at: <http://www.cercor.oxfordjournals.org/>.

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