Cortical Activations of Japanese-English Mental Translation Revealed By fMRI and MEG

Doctoral dissertation

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DOCTORAL DISSERTATION

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Abstract

The translation abilities of human beings far surpass those of computational devices, such as machine translators. However, very little is known about the translation processes in the human brain. A 148-channel magnetoencephalography (MEG) and a 1.5 T functional magnetic resonance imaging (fMRI) were used to investigate Japanese (L1) to English (L2) translation processes in the human brain. Healthy, right-handed Japanese subjects silently performed visual translations and visual repetitions of Japanese Hiragana words for experimental and comparable control conditions, respectively. MEG study in seven subjects suggested dynamic activations, starting from the right parieto-occipital sulcus (latency 150-250 ms) and the left collateral sulcus (latency 150-250 ms), to the left posterior superior temporal sulcus (latency 200-650 ms) and finishing at the left posterior lateral sulcus (Wernicke's area) (latency 350-450 ms). Whereas, fMRI study in six subjects indicated significant activations ($p > 0.0001$) in the left inferior frontal cortex (Broca's area and Insula) and supplementary motor area. It was concluded that L1 to L2 translation processes in the human brain consists of; character recognition of L1 in the right parieto-occipital sulcus, word recognition of L1 in the left collateral sulcus, word retrieval of L2 in the left posterior superior temporal sulcus, phonological processing of L2 in the left posterior lateral sulcus, semantic processing of L2 in the left inferior frontal cortex and inner speech planning of L2 in supplementary motor area.

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Chaiyapoj Netsiri

Contents

Chapter 1

Introduction

1.1 fMRI and MEG

In the past few years, neurosciences became the world-class research projects in the aim to understand the brain. Methods that are recently used for measurement brain activity are summarized in Fig. 1.1. To study human brain, the non-invasive measurement techniques are normally used. Among these techniques, functional magnetic resonance imaging (fMRI) and magnetoencephalography (MEG) are the promising and well-established techniques for non-invasively investigating brain activity with high spatial and temporal resolution.

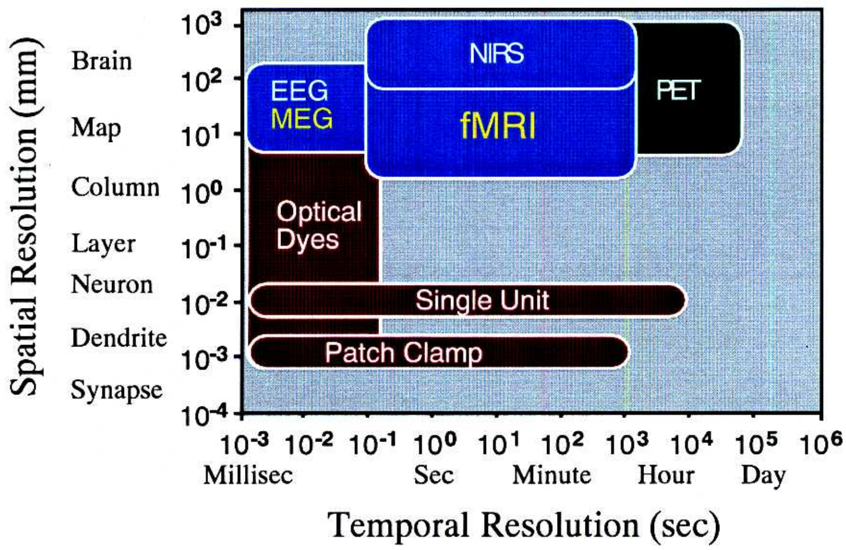


Fig. 1.1. Summary of methods used in neuroscience study (adapted from *Belliveau et al.* 1991). EEG = Electroencephalography, MEG = Magnetoencephalography, NIRS = Near Infrared Spectrometer, fMRI = Functional Magnetic Resonance Imaging, PET = Positron Emission Tomography.

It was not until 1973 when Hounsfield introduced x-ray computed tomograph (CT), that not only provided a new way of looking at the human brain *in vivo,* which had immense clinical significance, but it also stimulated the development of positron emission tomography (PET) by Ter-Pogossian et al. (1975), Phelps et al. (1975) and magnetic resonance imaging (MRI) by Lautebur (1973), Hinshaw et al. (1977), which made possible the imaging of brain function as well as anatomy[32]. PET has been used in humans to measure brain blood flow, blood volume, metabolism of glucose and oxygen, acid-base balance, receptor pharmacology, and transmitter metabolism. Petersen et al. (1988) introduced an initial approach for functional mapping of language processing of single word in healthy human subjects using PET[40,41].

Ogawa et al. (1992) and Kwong et al. (1992) demonstrated that neuronal functionally-induced signals could be obtained with MRI[32]. Because changes in functional activity are accompanied by focal changes in cerebral blood flow (CBF), blood volume (CBV), blood oxygenation, and metabolism, these physiological changes can be imaged to produce functional maps of mental operations[29].

Four parameters concerns the quality of functional mapping: (1) temporal resolution, (2) spatial resolution, (3) sensitivity[13] and (4) repetition of experiment. Methods based on PET and fMRI are limited in terms of time resolution. Spatial and temporal resolution of PET are limited at 6 mm and 30 s[14] and the repetition of experiment is limited by decay time of radio-active tracer which intravenously injected into the subject. On the other hand, an fMRI provides spatial and temporal resolution upto 1-3 mm and 1 s[14], higher signal-to-noise ratio[33] and unlimited repetition of experiment. However, the effect of high magnetic field (1.5 T to 4 T), using in the fMRI study, to the subject's body is not clearly understood.

Galvani's observations demonstrated that electrical activity serves as the basis of nerve and muscular activity[1]. In the 1870s, the physiologist C. Richard discovered changes of very weak current from the electrodes that placed on two points of the external surface or one electrode on the gray matter and one on the surface of the skull[1]. In 1929, H. Berger observed very weak electrical signals from electrodes which were placed on the scalp of human subject. The recording of the electrical signals from the brain is called the electroencephalography (EEG). The major limitations of EEG, however, are as follows: (1) the location of the reference electrode often affects the EEG data, (2) distant as well as nearby regions of brain tissue can contribute to the EEG at any given scalp location and the surface EEG is affected by the conductivity of intervening tissue so that sources are difficult to localize with any precision and (3) neural sources may fail to create appreciable potential differences parallel to the scalp, either because they comprise a "closed field" or because they are inappropriately oriented deep within sulci.

In 1963, Baule and McFee measured the first Magnetocardiography (MCG) signal, thus proving that it is possible to record magnetic activity generated within the body[1]. The first measurements of cerebral magnetic fields were reported by D. Cohen in 1968 and using a Superconducting QUantum Interference Device (SQUID) sensor in 1972[1]. The recording of magnetic field from the brain is called the magnetoencephalography (MEG). A significant portion of the initial work on MEG was done by S. Williamson and L. Kaufman.

Because no use of radioactive tracer or exposure of magnetic field to the subject's body, MEG measurement is completely safe. However, the MEG system is weak to the environmental noise and vibrations and consuming high-cost and unrecyclable liquid Helium.

1.2 Japanese-English mental translation

To answer a classical question on whether similar cerebral networks support the native and foreign language, a number of studies on multiple languages have focused on how different languages are represented in the human brain[8,23,24,25,39,42]. Although, a PET study reported that common neural substrates are involved in across language search[25], an fMRI study reported that separate neural substrate are involved in native and second language in late bilinguals[23]. However, very little is known about how the brain works across different languages. An approach to this question is the investigation of the translation process because the same information from one language is transferred to another language during translation.

Coherence analysis of electroencephalography (EEG) signals in three professional interpreters while mentally interpreting sentences from a native language (L1 = German) to foreign languages (L2 = English/French) and vice versa demonstrated that significant differences appeared in the temporal region of the dominant hemisphere[42]. However, this study could not identify brain areas that activated by mental interpretation. A PET study of the translation of a single word from L1 (English) to L2 (French) and vice versa in English-French bilinguals suggested a common activation of the left inferior frontal cortex (LIFC) in semantic search of within- and across-language[25]. Both studies[25,42], investigated bilinguals by auditory stimulation only. Therefore, an obvious question is whether similar cortical correlates of the same process are activated in bilinguals of other languages by stimulations of other modalities.

FMRI demonstrated high enough spatial resolution to discriminate distinct cortical areas of L1 and L2 in the sub-area of LIFC (Broca's area) in late bilinguals[23], anatomical variability in the cortical representation of L1 and L2[8] and cerebral organization of English-American Sign Language bilinguals[34]. Using free sentence generation task in either L1 or L2, an fMRI study, using a 1.5 T MR scanner, suggested distinct cortical areas associated with L1 and L2 in Broca's area of late bilinguals (exposed to a second language in early adulthood)[23]. Listening to stories in L1 and L2, another fMRI study using a 3 T MR scanner supported a hypothesis that L1 acquisition relies on a left hemisphere while late L2 acquisition is not necessarily associated with a reproducible biological substrate[8].

MEG demonstrated high enough temporal resolution to indicate dynamics of brain activation during picture naming[50] and processing of visually presented Japanese characters[27,28]. Using covert and overt naming task, an MEG study, using a 122 channel whole-head SQUID magnetometer, demonstrated the dynamic conversion from visual to symbolic representation progressed bilaterally from the occipital cortex towards temporal and frontal lobes[50]. Another MEG study using a dual 37 channel SQUID magnetometer, suggested that the left occipito-temporal lingual and fusiform gyrus mediates the neural function subserves the specific visual word processing and/or general analysis of visual form[28].

Therefore, with an integration of fMRI and MEG studies, the process in question, a translation process, can be scrutinized with the complementary advantages of each technique.

In the present study, a 148-channel MEG and a 1.5 T fMRI were used to investigate Japanese (L1) to English (L2) translation processes in the human brain.

Two kinds of experiments were conducted in fMRI study: Experiment 1, a visual translation task of randomized single words which reflected the translation process of Japanese words and, Experiment 2, an Arabic numeral reading task. The latter was added because the subjects reported that they read stimuli in Japanese (L1) before translating them to English (L2) in Experiment 1. This action may cause undesirable activation due to large differences in the length of inner speech.

Four kinds of experiments were conducted in MEG study: a visual translation of randomized single words, a visual translation of categorized single words, a visual word repetition of randomized single words and a visual noun-verb generation of randomized single words. Translation of both randomized and categorized words are considered to be test conditions while repetition of words is considered to be a comparable control condition. Effect of category on brain activity and reaction time can be investigated from difference between translation of randomized and categorized words as well. Noun-verb generation is considered to be a similar task to the translation task.

Chapter 2

Cognitive model of mental translation

A cognitive model of mental translation derived by a step-by-step development originally from a cognitive model of word and image (word-image model), then, a cognitive model of native and second language model (L1-L2 model).

2.1 Word-image model

Psychological studies[44,45] suggested that time to read words in native language (L1) such as かぎ ("kagi"=key) is 200-300 ms faster than time to name the pictures of key. However, in the category matching task of words and pictures to their superordinate categories, the reaction times (RT) are as fast (or faster) as to picture as to words. Approximately equal RTs from category matching task indicated two equal connections from words and images to a common semantic memory. The reason, that RT for reading words in L1 is shorter than naming image is, words can be directly converted to sound (phonological processing) without access to the meaning (semantic processing). A word-image model as shown in Fig. 2.1 was proposed .

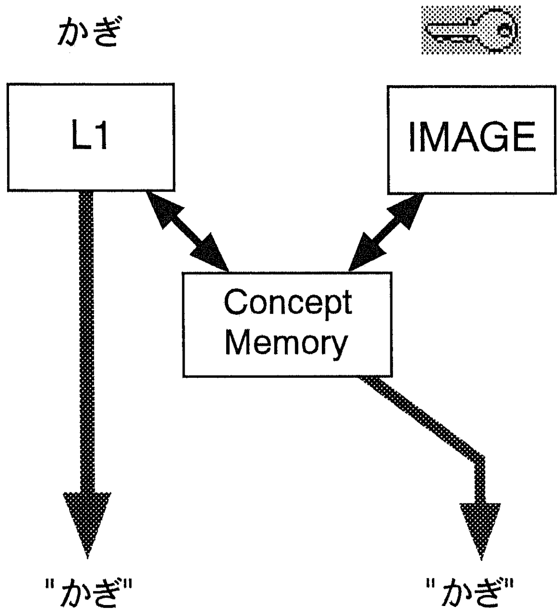


Fig. 2.1. A cognitive model of a common semantic memory of words and images (adapted from *Potter et al.* 1984).

2.2 L1-L2 model

The first explicit test of hypotheses for mapping L1 to L2 words to concepts was reported by Potter et al. (1984)[7,45]. According to several studies, there are two possible connections which provide word association model as shown in Fig. 2.2. or concept mediation model (shared representation model[6]) as shown in Fig. 2.3. RTs for naming pictures in L2 and translating L1 to L2 were used for interpretation. Instead, if RT for naming pictures in L2 is longer than for translating L1 to L2, the word association model is valid and if RT for naming pictures in L2 is approximately equal to RT for translating L1 to L2, the concept mediation model is valid.

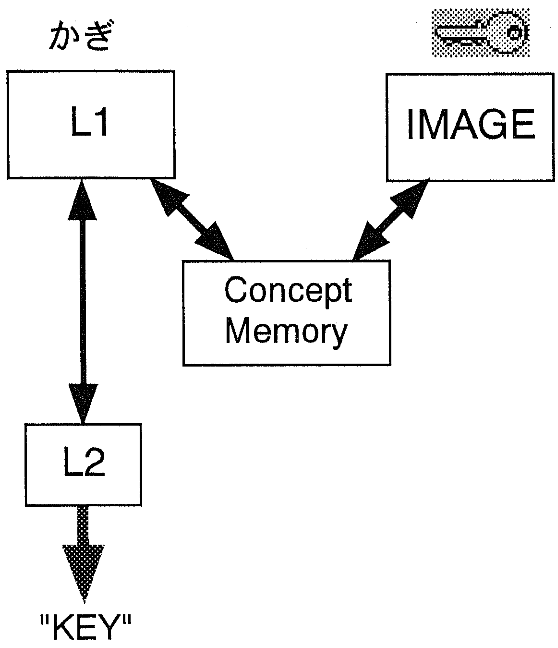


Fig. 2.2. A word association model of native and second language and image.

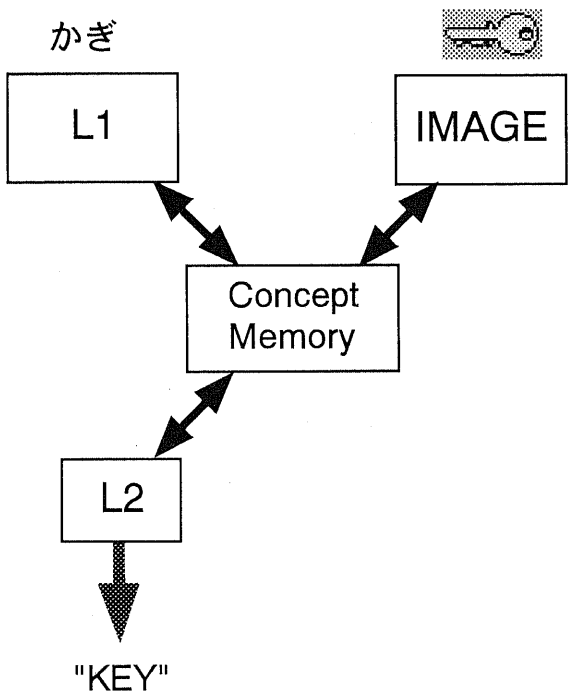


Fig. 2.3. A concept mediation model of native and second language and image.

Although, several studies supported the concept mediation model[7], this model could not explain longer RT of forward translation (L1 to L2) than RT of backward translation (L2 to L1). Kroll et al. (1994) manipulated levels of semantic accesses by using categorized and randomized words for translations and found category interference in forward translation[26]. An asymmetrical model of L1 and L2[26] was proposed with an explanation of strong semantic access in forward translation and strong lexical access in backward translation as shown in Fig. 2.4. The other psychological study in more fluent and less fluent bilinguals also supported this model and suggested less nodes of common semantic memory for both L1 and L2 in less fluent bilinguals than in more fluent bilinguals[11].

2.3 Mental translation model

Since larger effects of semantic word variables in L1 to L2 translation[6], an asymmetrical model of L1 and L2 as shown in Fig. 2.4 can be modified to a cognitive process of mental translation of Japanese-English (L1 to L2) as shown in Fig. 2.5. This model indicates the mapping of orthographic and phonological memory from L1 to L2 (the top layer in Fig. 2.5) through a common semantic memory (the bottom layer in Fig. 2.5).

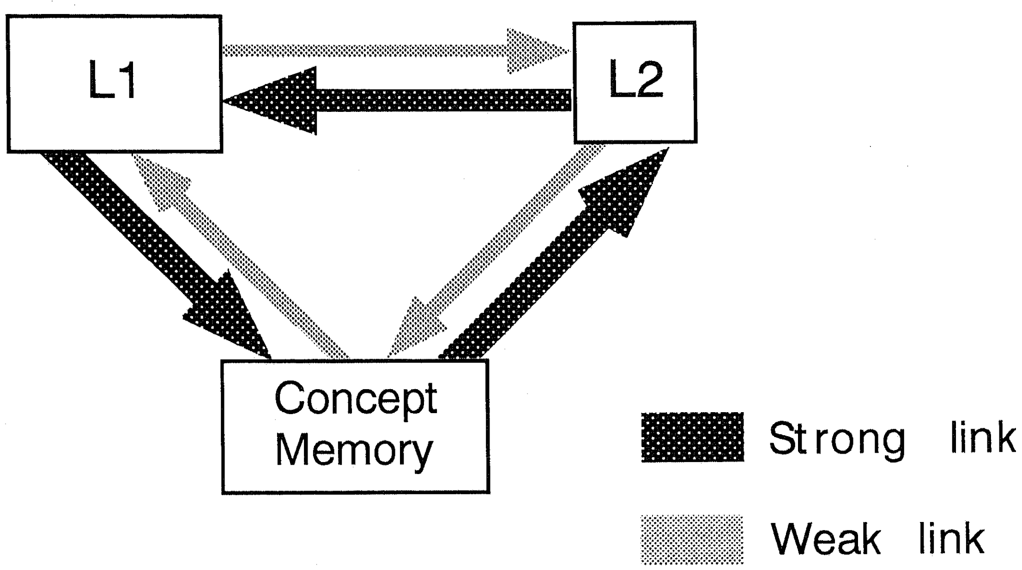


Fig. 2.4. An asymmetric model of native and second language.

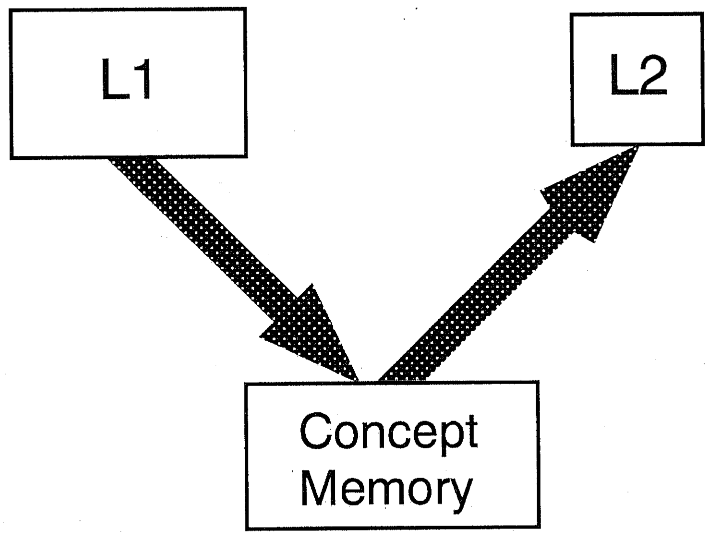


Fig. 2.5. A proposed model of Japanese-English mental translation.

Chapter 3

fMRI study on Japanese-English mental translation

3.1 Functional mapping by fMRI

FMRI signal is originated from the change of MR signal due to brain activation. Whenever neurons are activated, the local hemodynamic changes which results in increase of local blood flow and decrease of local deoxygenated red blood cell concentration. The chemical equivalent equation of deoxygenated Hemoglobin (DeoxyHb) and oxygenated hemoglobin (OxyHb) can be expressed as follows:

$$\underset{\substack{\text{DeoxyHb} \\ \text{(Paramagnetic)}}}{Hb(Fe^{2+})+O_2} \rightleftarrows \underset{\substack{\text{OxyHb} \\ \text{(Diamagnetic)}}}{Hb(Fe^{2+}) \cdot O_2} \tag{3.1}$$

Magnetic properties of DeoxyHb and Oxy Hb are paramagnetic and diamagnetic, respectively. Ogawa et al. (1990) demonstrated that MR signal in the vicinity of vessels and in perfused brain tissue decreased with a decreasing in blood oxygenation[36]. This type of physiological contrast was coined blood oxygenation level dependent (BOLD) contrast[36]. A reduction in DeoxyHb in the vasulature causes a reduction in susceptibility differences causing an increase in MR signal in T2*-weighted MR images. Using statistical analysis, the local significant changes of MR signals provide functional map of the brain[32].

3.2 Cognitive subtraction

In psychological aspect, cognitive processes are supposed to be linear and hierarchical and are arranged from lower to higher function. A cognitive process of interest (POI) can be separated by a cognitive subtraction[13] with ignorable mutual interaction among processes. A cognitive subtraction stands for a method of subtracting the response of control task (control condition) from experimental task (test condition) as shown in Fig. 3.1. POI can be obtained from

$$POI = TEST - CONTROL \tag{3.2}$$

In the present study, fMRI signals acquired from MR scanner during experiment is defined as measured responses in test and control condition.

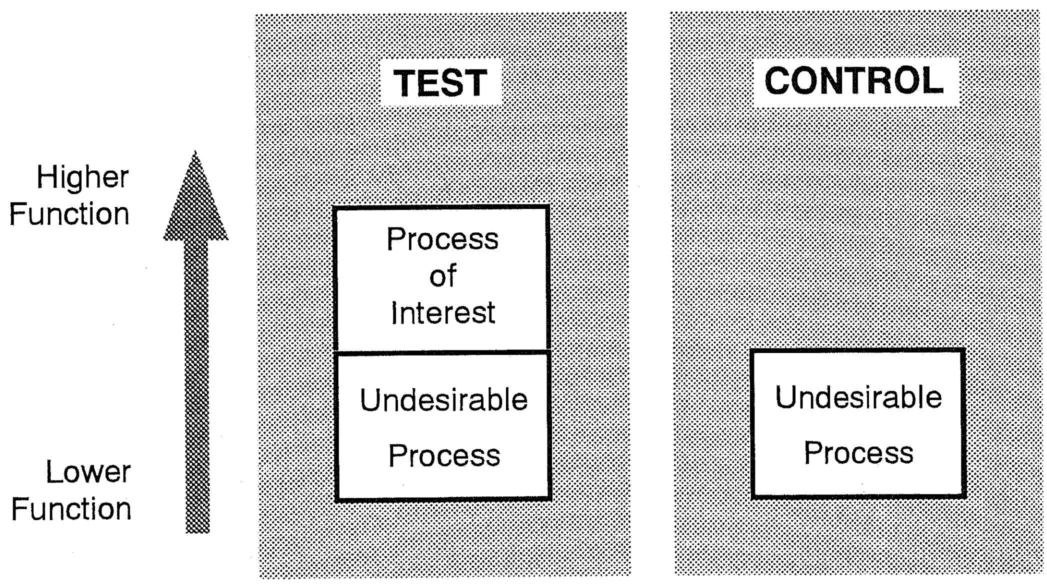


Fig. 3.1. Block diagram of cognitive processes in test and control conditions.

3.3 Method

Subjects

Three male (subject A, B and C) and three female (subject D, E and F) volunteers (n = 6) with ages ranging from 22 to 44, mean age (M) of 27.3 and standard deviation (SD) of 3.5, and academic backgrounds from a 3rd-year college level to a Ph.D. level participated in Experiment 1 (translation). They were right-handed with a mean laterality quotient (L.Q.) of +87 and a mean decile of R.6 as assessed by the Edinburgh Inventory[38] and healthy native Japanese speakers with no history of neurological disease. The subjects received visual corrections prior to the experiments.

The laterality quotient (L.Q.) is calculated by

$$L.Q. = 100\,\frac{\sum_{i=1}^{10} X(i,R) - \sum_{i=1}^{10} X(i,L)}{\sum_{i=1}^{10} X(i,R) + \sum_{i=1}^{10} X(i,L)} \qquad (3.3)$$

$$-100 \leqq L.Q. \leqq 100$$

where $X(i, R)$ and $X(i, L)$ are either 0, 1 or 2. A handedness test consists of 10 test items (i) of using right or left hand of the subject in a specific task such as drawing a picture. In a test item, 0, 1 and 2 stand for no use, bilateral (both R and L) and unilateral (R or L only) use of the subject's hands.

The subjects started to learn English as a second language in school at the age of twelve and none had lived in an English-speaking country for more than one year. Two male(subject B and G) and one female (subject E) volunteers (n = 3) ranging in age from 22 to 25 (M = 23 years, SD = 1) participated in Experiment 2 (numeral reading). All subjects gave informed consent before MRI scanning. The experiments were performed under the approval of the institution (Communications Research Laboratory, Ministry of Posts and Telecommunications, Japan).

Scanning Methods

MR images were acquired using a 1.5 T whole body MRI scanner (Siemens Magnetom Vision) with an Echo Planar Imaging (EPI) booster. The scanner is shown in Fig. 3.2. Sixteen-slice functional images were scanned every 5 s and the stimuli were presented every 2.5 s. A T2*-weighted gradient echo sequence was used (TE 66 ms, flip angle 90°, matrix 128 x 128, FOV 280 mm, slice thickness 7 mm, distance factor 0.4, pixel size 2.18 x 2.18 mm, transverse orientation) which covered the subjects's cerebrum and cerebellum. Locations of slices are determined by a localizer as shown in Fig. 3.3.

One scanning session consisted of 120 tasks and 4 dummy scans. The 120 task scans were divided into 12 alternating blocks of test and control conditions, each consisting of 10 consecutive scans and 4 dummy scans, half of which placed before and after the task scan. Sixteen structural images for anatomical identification were acquired at the same location as the functional images using a gradient echo sequence (TR 240 ms, TE 6 ms, flip angle 90°, matrix 256 x 256, FOV 280 mm, pixel size 1.09 mm, slice thickness 7 mm, distance factor 0.4, transverse orientation) and two hundred slices of the subjects's whole-head were acquired for orthogonal multiplanar reconstruction (TR 9.7 ms, TE 4 ms, flip angle 12°, matrix 256 x 256, FOV 256 mm, pixel size 1 mm, slice thickness 1 mm, distance factor 0, sagittal orientation). Examples of functional and structural images are shown in Fig. 3.4 and Fig. 3.5, respectively.

Paradigm design

Experiments 1 and 2 were designed to detect the contrasts of the translation of Japanese single words (test) from word repetition of Japanese single words (control) and from long (test) and short (control) inner speech, respectively.

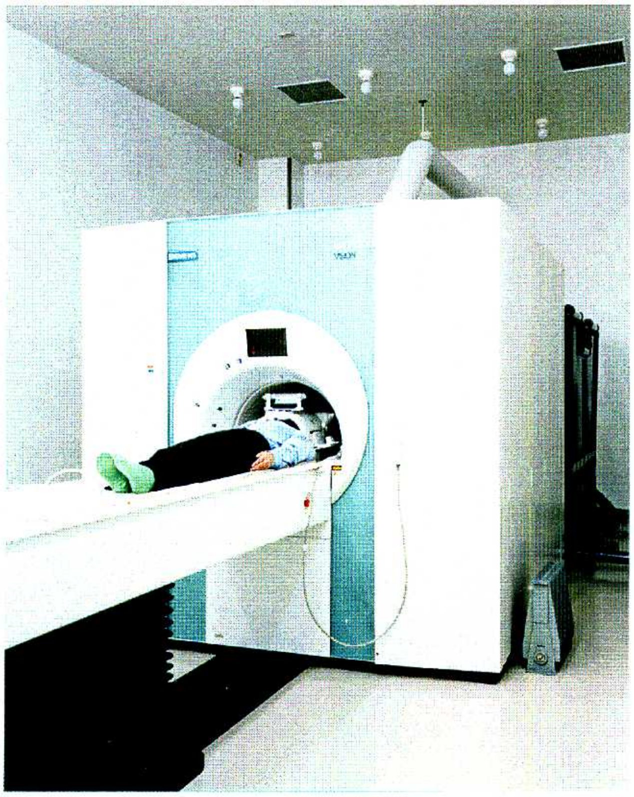


Fig. 3.2. A 1.5 T MRI scanner which was used in this study.

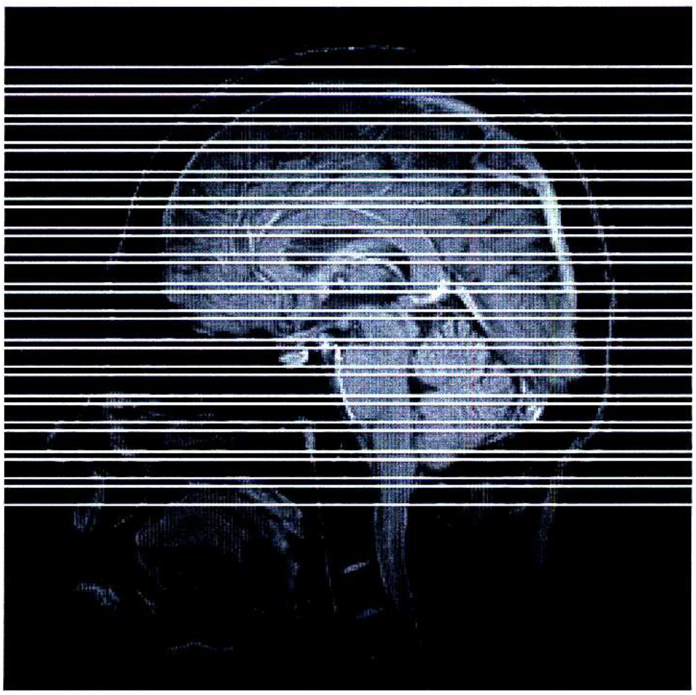


Fig. 3.3. Locations of sixteen slices which covered the subject's cerebrum and cerebellum.

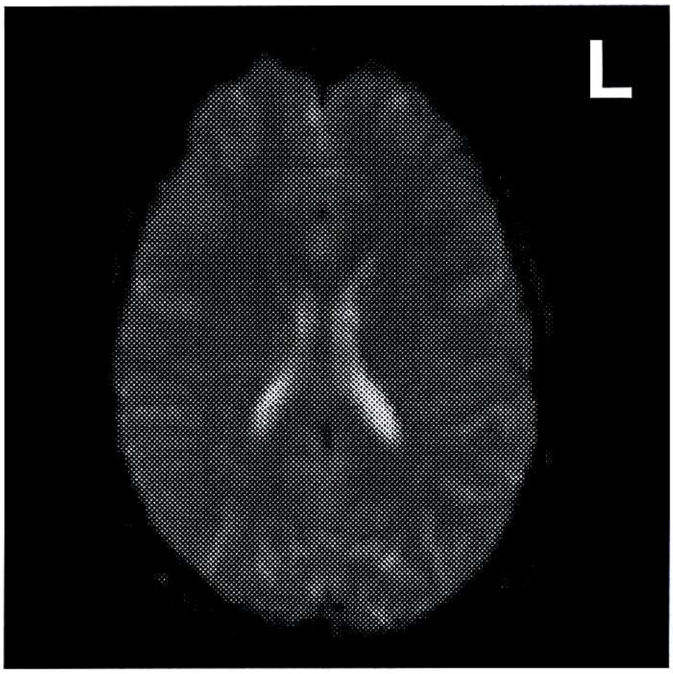


Fig. 3.4. A functional image in transverse orientation. L = Left side.

Fig. 3.5. A structural image in transverse orientation. L = Left side.

Stimuli and responses

During the experiments, the subjects saw 240 stimuli which were either Japanese Hiragana phonograms having two characters (Experiment 1) or Arabic numerals having 4 digits (Experiment 2). Stimuli were generated by a personal computer (NEC PC-9821) and visually presented via a projector (SONY VPH-1272QJ) onto a semi-transparent screen below a 0.3° x 0.3° fixation point with visual angles of 2.6° horizontally and 1.3° vertically. A brief (500 ms) instruction, which indicated the test or control condition, was visually presented above a fixation point at the beginning of each condition. The timing diagram of instruction, stimulus, reaction time and MR scanning is shown in Fig. 3.6. The brightness of the stimuli and background were 15 and 0.5 cd/m^2, respectively. Stimuli were presented at a 1 s duration and a 2.5 s interstimulus interval (ISI). Subjects in the supine positions viewed stimuli through a tilted non-magnetic mirror attached to the head coil.

The stimuli used in Experiment 1 were familiar nouns consisting of two Hiragana characters and two syllables. The stimuli used in Experiment 2 consisted of 4-digit Arabic numbers. The first and the fourth digits were randomly changed, but the second and third digits were fixed as “88” or “00” in the test and control conditions, respectively, providing a large difference in length of inner speech.

The subjects were instructed to silently read and respond to the stimuli to avoid head movement. Reaction times were recorded simultaneously during fMRI experiments for behavioral studies in both experiments. A reaction button was pressed with the left index finger after finishing mental translation or repetition task. The examples of stimuli and responses are shown in Table 3.1. Short practice sessions were given prior to the experiments.

	EXPERIMENT 1		EXPERIMENT 2	
	Stimulus	Response	Stimulus	Response
TEST	ねこ ("neko")	"cat" button-press	1881	"sen-happyaku hachijuu-ichi" button-press
CONTROL	ほん ("hon")	"hon" button-press	1001	"sen-ichi" button-press

Table 3.1. Example of Experiment 1 (Translation) and Experiment 2 (Inner speech).

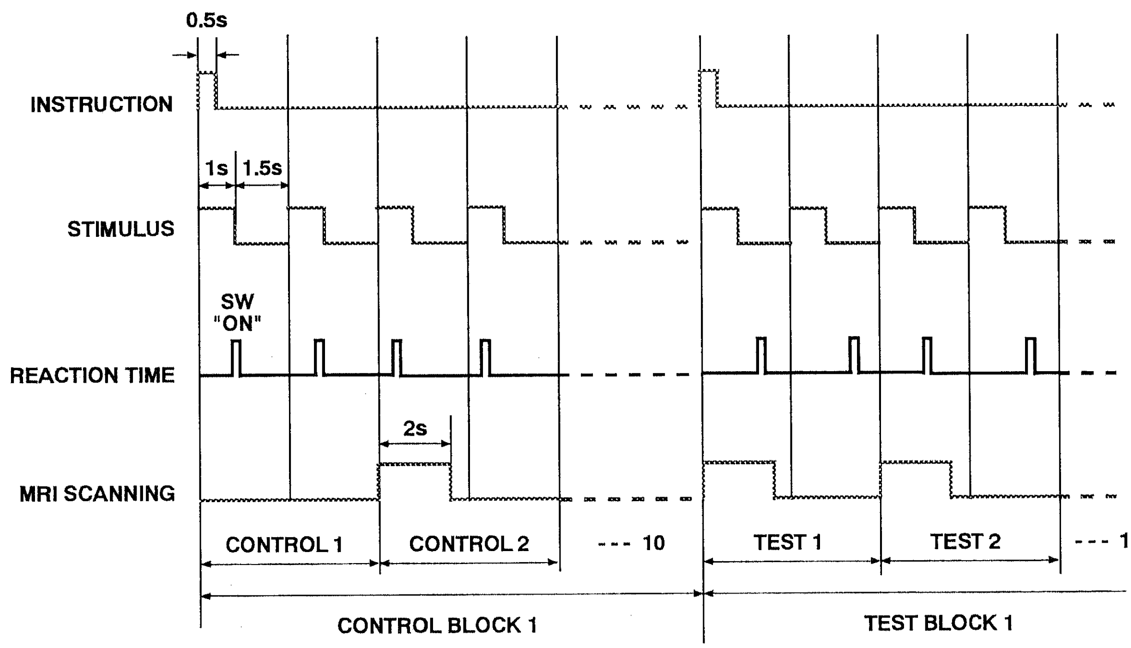


Fig. 3.6. Timing diagram of fMRI experiment.

Head movement

Since head movement deteriorates fMRI signals, we used individual bite bars and motion correction of raw fMRI data by Automated Image Registration[56](AIR) Ver. 3.0.

Data analysis

A correlation coefficient method[2] (*cc*) was used on AVS Release 5 (Advanced Visual Systems, Inc.) to evaluate whether each pixel of fMRI data showed any significant change at $cc > 0.35$ ($p < 0.0001$). Subjects' gyri and sulci were identified by multiplanar reconstruction using OSIRIS Ver. 3.1 (University Hospital of Geneva). The subjects' whole-head MR images were registered to Talairach coordinates[51] by MEDx Ver. 2.1 (Sensory Systems, Inc.). Only significant pixels which had more than two clustered pixels were considered for localization of activated brain areas.

Correlation coefficient can be calculated by the following expression[2]:

$$cc = \frac{\sum_{i=1}^{N} (r_i - \bar{r}_i)(x_i - \bar{x}_i)}{\sqrt{\sum_{i=1}^{N} (r_i - \bar{r}_i)^2} \sqrt{\sum_{i=1}^{N} (x_i - \bar{x}_i)^2}} \tag{3.4}$$

where N is the number of fMRI scans (N=120), r is the reference function of test and control (Box-car waveform) and x is the raw fMRI data.

3.4 Results

Behavioral study

From the behavioral data, an analysis of variance (ANOVA) using StatView Ver. 4.5 (Abacus Concepts, Inc.) indicated that the subjects (N=6) were significantly slower at the Japanese-English word translation task (ENG) than the Japanese word repetition task (JPN), degree of freedom (df) = 5, $F(1,5) = 65.9$, $p < 0.0001$ as shown in Fig. 3.7. The mean reaction time (RT) for the word translation task was 1,117 ms (SD = 374) and 523 ms (SD = 256) for the word repetition task.

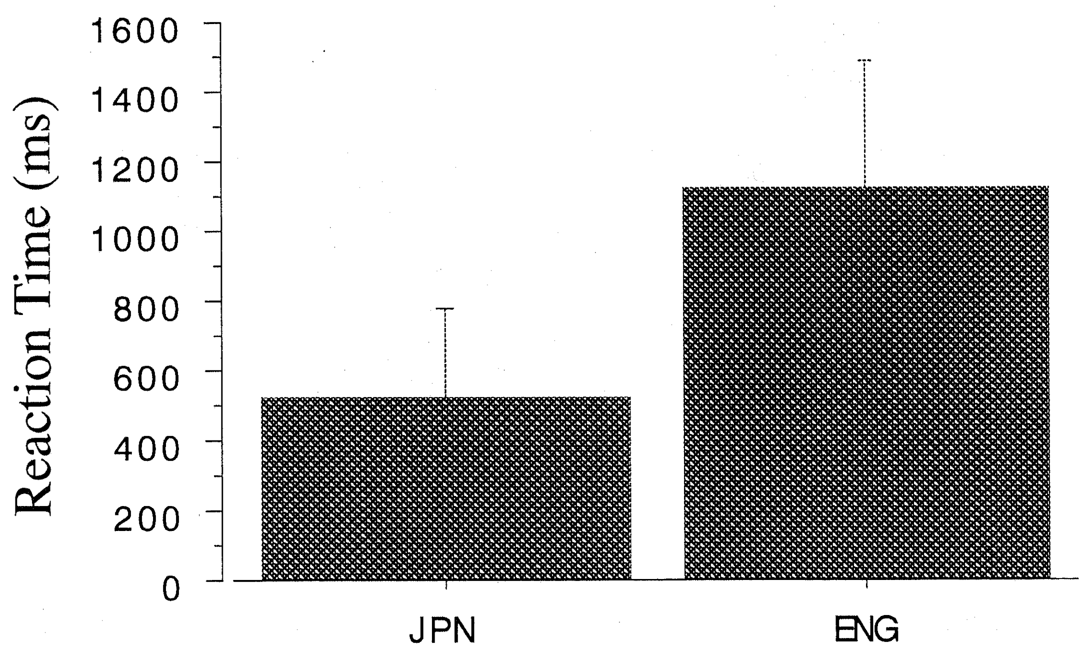


Fig. 3.7. Reaction times of Japanese word repetition (JPN) and Japanese-English word translation (ENG).

The subjects (N=3) were also significantly slower at numeral reading for long inner speech (LONG) than short inner speech (SHORT), df = 2, $F(1,2) = 72.89$, $p < 0.0001$ as shown in Fig. 3.8. The RT for short inner speech was 1,124 ms (SD = 373) and 1,656 ms (SD = 272) for long inner speech.

These results indicated that the subjects used different processes in the test and control conditions.

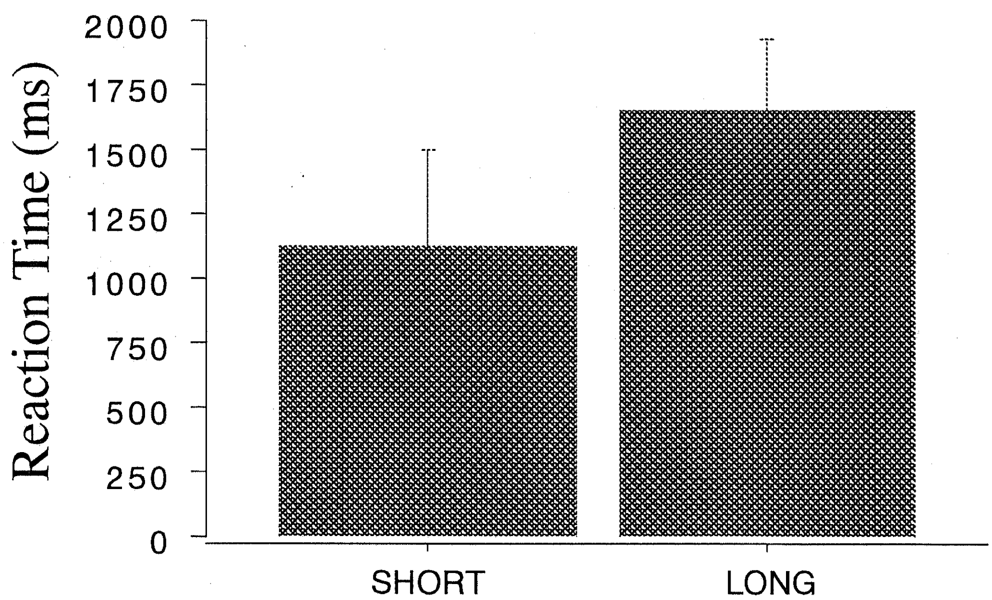


Fig. 3.8. Reaction times of short inner speech (SHORT) and long inner speech (LONG).

MRI study

From Experiment 1, significant activations were commonly observed in more than three subjects in the bilateral supplementary motor area (LSMA and RSMA)(medial side of BA 6), the left precentral cortex (LPCC)(lateral side of BA 6), the bilateral prefrontal cortex (LPFC and RPFC) (BA 9/10/46), the left inferior frontal cortex (LIFC) (Broca's area and Insula) and the left intraparietal sulcus (LIPS). Foci of the activations in three representative subjects were selected from the maximum *cc* of each area as shown in Fig. 3.9. The corresponding Tarailach coordinates of each focus are shown in Table 2. The number of activated pixels with standard deviation and brain areas of 6 subjects are shown in Fig. 3.10(a). The activation of LSMA and LPCC, and LIFC was significantly larger than RSMA and RPCC ($p < 0.006$), and RIFC ($p < 0.0001$), respectively. The total number of activated pixels indicated that the left-hemisphere was significantly more activated than the right-hemisphere ($p < 0.0001$) as shown in Fig. 3.10(b). No significant activations found in Experiment 2. The result of 3 subjects in Experiment 2 is shown in Fig. 3.11.

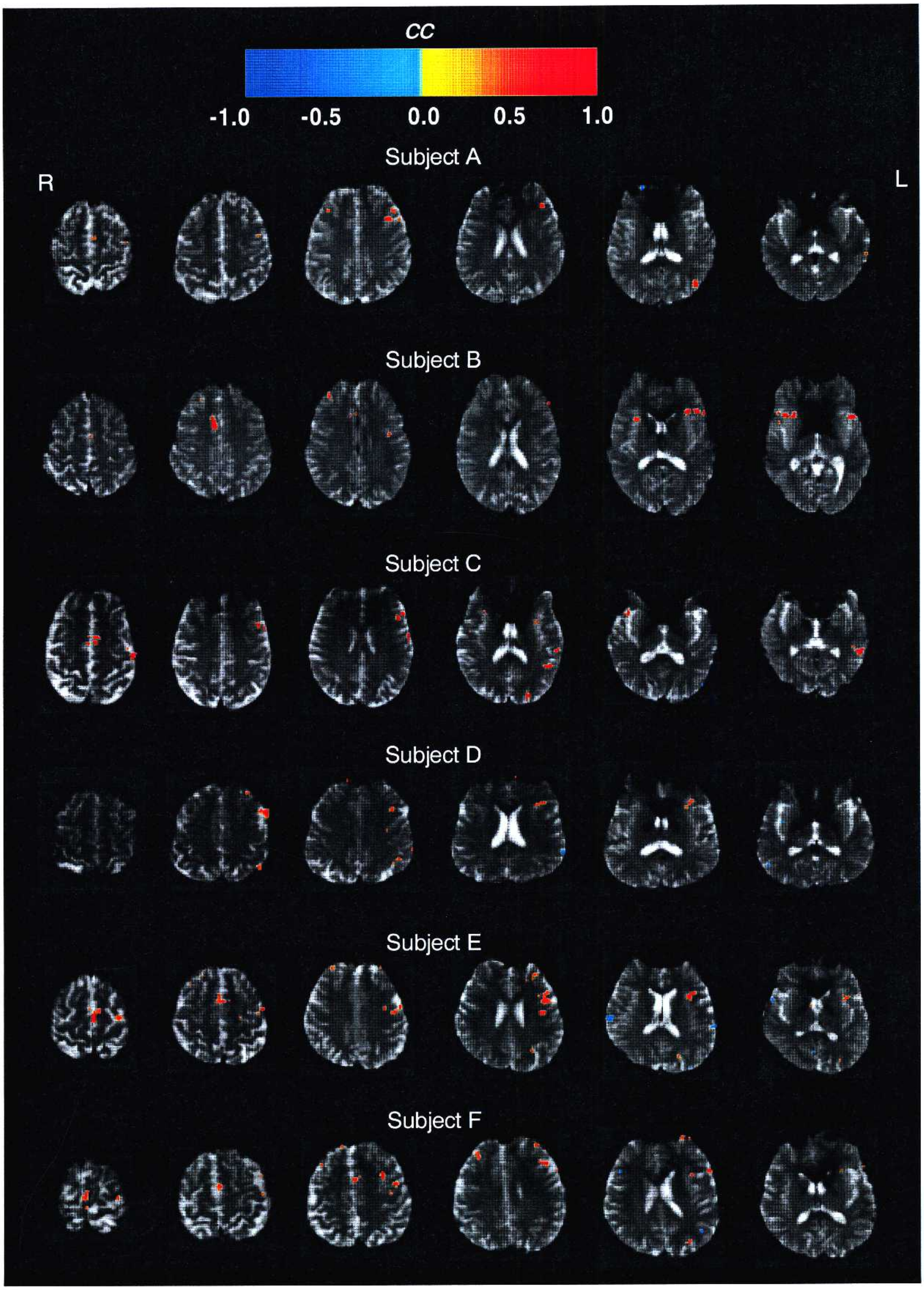
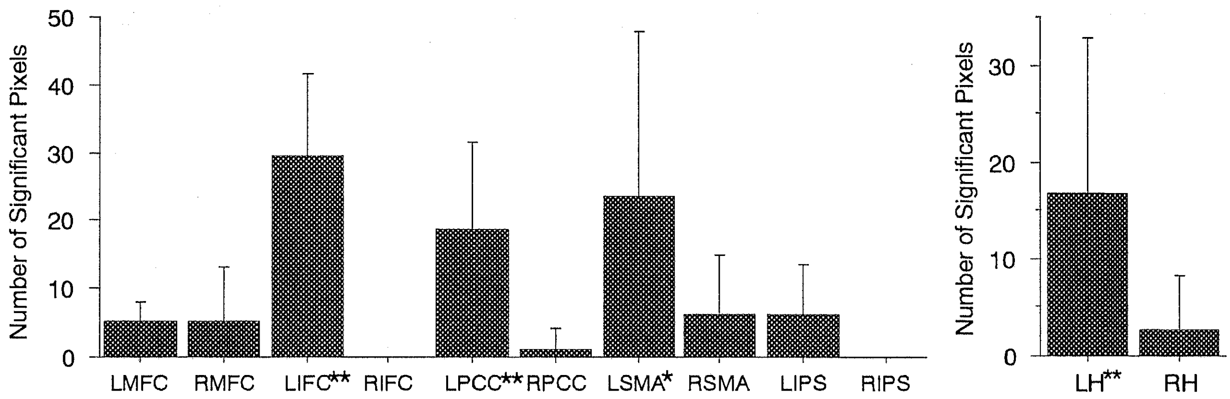


Fig. 3.9. Significant activation ($p < 0.0001$) of six subjects during mental Japanese-English translation. *cc* = Correlation coefficient. L = Left, R = Right.

Brain Area	Subject A				Subject D				Subject E			
	x	*y*	*z*	*cc*	*x*	*y*	*z*	*cc*	*x*	*y*	*z*	*cc*
LSMA (BA6 Medial)	-6	-4	56	0.48	-2	-2	48	0.69	-2	-8	62	0.62
RSMA (BA6 Medial)	-	-	-	-	4	10	40	0.51	-	-	-	-
LPCC (BA6 Lateral)	-48	-8	44	0.59	-40	-12	48	0.52	-40	-6	58	0.65
LPFC (BA9/10/46)	-46	24	36	0.47	-20	54	26	0.5	-36	48	22	0.52
RPFC(BA9/10/46)	38	38	36	0.59	32	38	40	0.46	28	38	32	0.54
LIFC (BA45)	-44	34	20	0.62	-44	18	24	0.57	-48	24	22	0.6
LIPS(BA39)	-	-	-	-	-24	-64	22	0.49	-30	-78	24	0.53

Table 3.2. Foci of activation of three representative subjects during translation of Japanese to English single words. The stereotactic coordinates in mm (*x, y, z*) of subjects were obtained separately from their standard Talairach space. LSMA = Left supplementary motor area, LPCC = Left precentral cortex, LMFC = Left middle frontal cortex, RMFC = Right middle frontal cortex, LIFC = Left inferior frontal cortex, LIPL = Left inferior parietal lobe, BA = Brodmann's area, *cc* = Correlation coefficient.



(a) **(b)**

Fig. 3.10. (a): Number of significant pixels with standard deviation and brain areas in six subjects during translation of Japanese to English single words. **(b)**: Total number of significat pixels with standard deviation and left (LH) and right hemispheres (RH). *L > R, $p < 0.006$, **L > R, $p < 0.0001$.

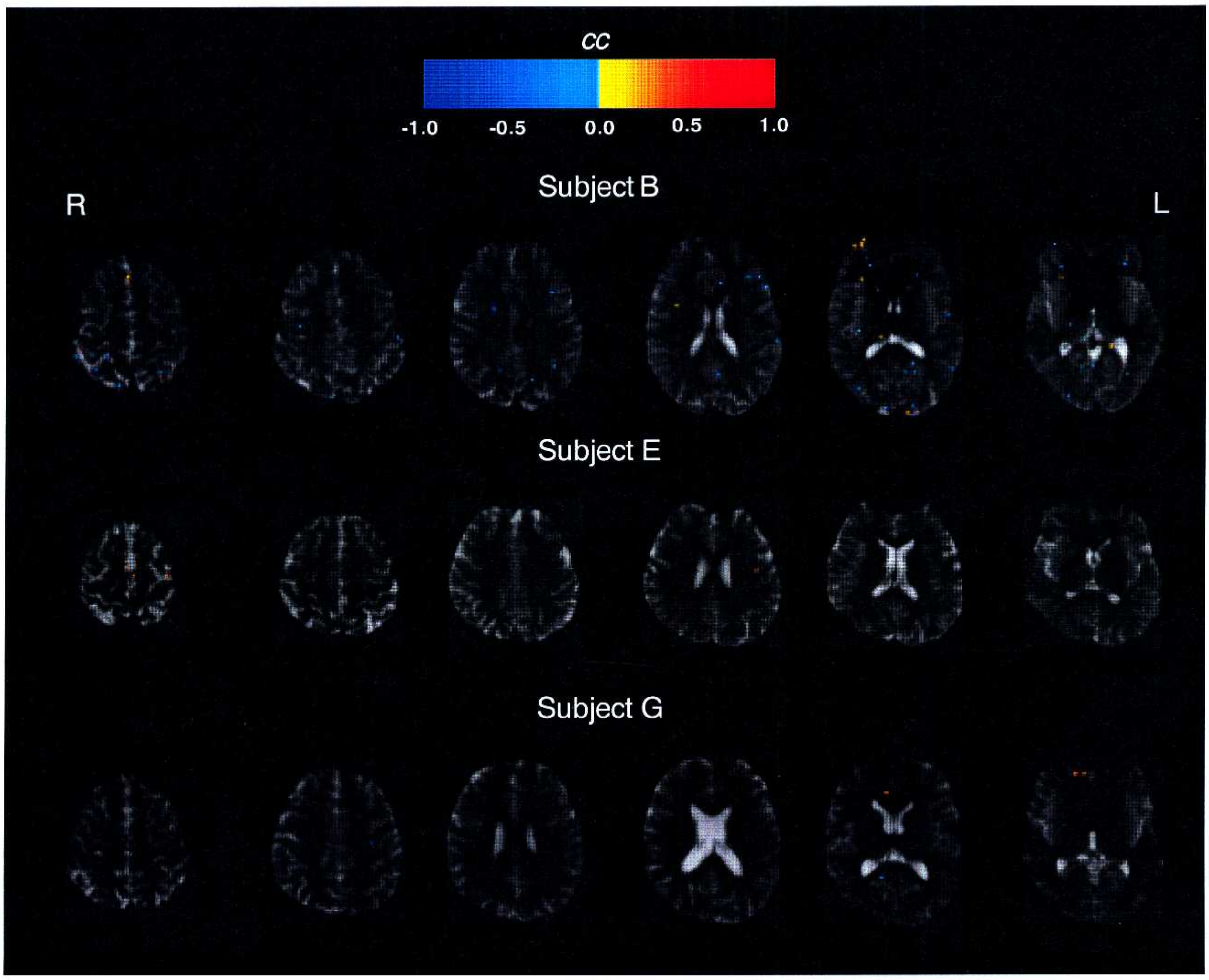


Fig. 3.11. Significant activation ($p < 0.0001$) of three subjects during Arabic number reading task. *cc* = Correlation coefficient. L = Left, R = Right.

3.5 Discussion

In the previous PET study[25], overt translation of auditory stimuli from L1 to L2 activated the left inferior frontal cortex (BA45,11/47), left superior frontal cortex (BA8 medial and lateral side), left inferior temporal cortex (BA37/20), left inferior parietal cortex (BA7), cerebellum (vermis and right side) and left putamen across twelve subjects. Using fMRI in the present study, we observed activation which correlated to the mental translation of visually presented L1 to L2 in LIFC (BA44/45/ anterior Insula), LPCC (BA6 lateral side), LPFC and RPFC (BA9/10/46), LSMA and RSMA (BA6 medial side), and LIPS.

Only activation of BA45 was consistent with the previous PET study[25]. Although, the Insula and Broca's area (BA44, 45) were considered to be active for inner speech[21,31]. Experiment 2 showed no significant activation in the BA45 for the contrast of long and short inner speech conditions. Hence, it was demonstrated that the difference in the length of inner speech did not affect activation of LIFC in the present study. The role of BA45 was considered to be a semantic search during translation in the previous study[25]. Furthermore, several other studies[46] demonstrated that the left frontal cortex which included BA9, 10, 11, 44, 45, 46, 47, was associated with semantic processing in word generation[21,30,40,41,54,37], sentence generation[23,31], semantic judgment[9], semantic priming task[53] and common semantic system for words and pictures[52]. Thus, it is very probable that the LIFC mediates semantic search during mental translation.

We observed activation in LPFC and RPFC (BA9/10/46). Bilateral activation of these areas were observed using a verbal working memory task[43], a short-term maintenance task of verbal information[12] and memory retrieval task[22] in other PET studies. For a noun-verb generation, a hypothesis was proposed that semantic information of the noun must be held in the working memory to generate a verb[18]. Therefore, we postulated that the activations of LPFC and RPFC may reflect the working memory that maintains information of L1 while searching for appropriate words in L2. Activation of these areas, however, were not found in the previous PET study[25]. A possible explanation was that the moderate second language abilities of our subjects increased the demands of the verbal working memory in comparison to the highly proficient subjects in the previous study[25]. The supplementary motor area demonstrated a correlation to motor planning of inner speech in the silent verb generation[55]. The present activation in LSMA and RSMA, which was not detected in the previous study[25], may be due to the larger task demand of motor planning for articulating L2 in our subjects who were moderately proficient in L2.

In contrast to the previous study[25], activations of the areas of BA11/47, 8, 37/20, and 7, the left putamen, left inferior temporal cortex and cerebellum were not observed in the present study. There are four possibilities to explain why these areas were not activated: (1) the difference between auditory and visual presentation of stimulus, (2) the difference between overt and silent responses, (3) the different sensitivity and spatial resolutions between PET and fMRI and (4) the difference between high and moderate levels of second language proficiency of the subjects.

The data indicated that the left-hemisphere was significantly more activated than the right hemisphere for the six subjects who were right-handed. However, the roles of LPCC and LIPS were unknown in the present study.

Chapter 4

MEG study of Japanese-English mental translation

4.1 Neuromagnetic field measurement by MEG

Neuromagnetic field is supposed to be generated from the currents which flow through dendrites of brain neurons[48], especially, pyramidal cells which oriented tangentially (rather than at right angles) to the scalp as shown in Fig. 4.1. This implies that if the cortical generators are oriented perpendicular to the cortical surface, neurons in sulci[48] rather than gyri will be the major contributors to the neuromagnetic field. Fig. 4.2 shows the MEG measurement using a magnetometer in the present study.

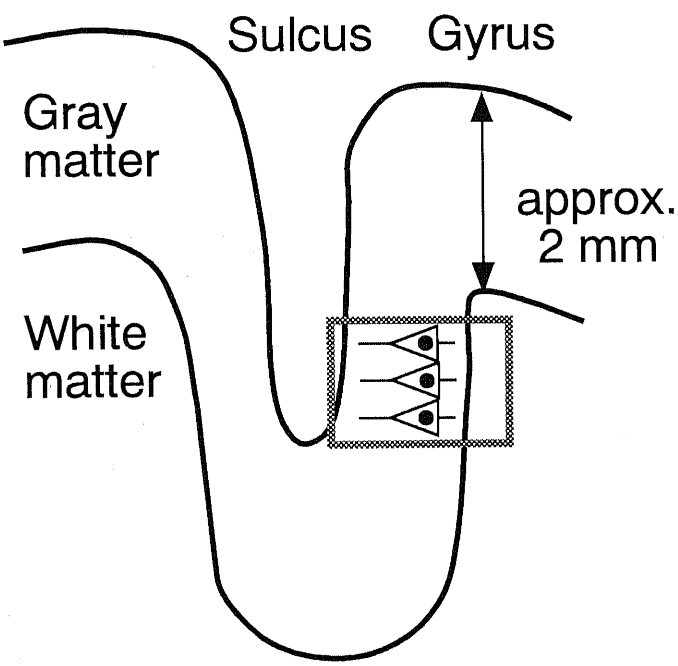


Fig. 4.1. Tangential orientation of cortical pyramidal cells which generate MEG signals due to their electrical activities.

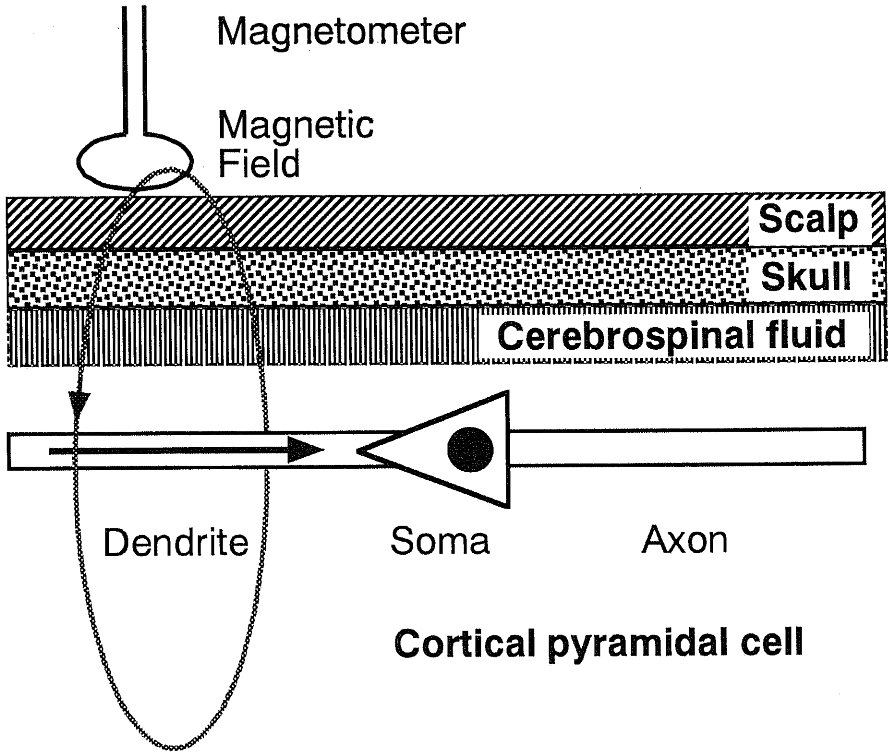


Fig. 4.2. MEG measurement of neuronal activity using a magnetometer.

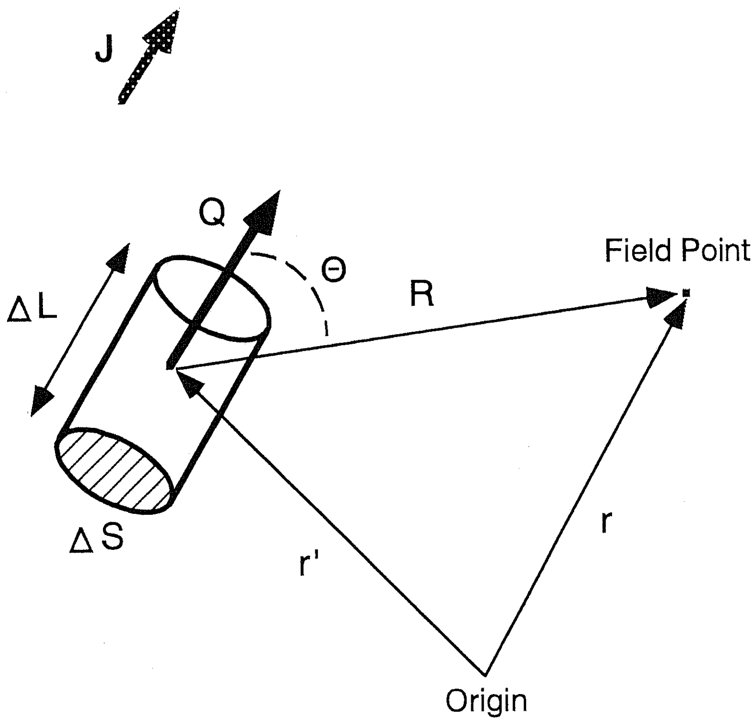


Fig. 4.3. Magnetic field at a measured point.

Currents and fields

When a current flows as shown in Fig. 4.3, it produces a magnetic field **H**. According to the right hand rule, the fingers curve in the direction of H if the thumb is in the direction of the current I. The magnetic field strength decreases inversely with the distance

$$H(r) = I/(2\pi r) \tag{4.1}$$

(Ampére's law). The moment **Q** of the current dipole, is given by the current density **J** and the volume of the element

$$\mathbf{Q} = \mathbf{J}\,\Delta l\,\Delta s \tag{4.2}$$

where Δl and Δs are the length and cross-sectional area of conductor, respectively as shown in Fig. 4.3.

According to Biot-Savart's law, the magnetic flux density at any position determined by vector **R** is given by

$$\mathbf{B}(\mathbf{r}) = \mu_0/(4\pi R^3)^{-1}\mathbf{Q} \times \mathbf{R} \tag{4.3}$$

where μ_0 is the permeability of free space.

4.2 Method

Subjects

Four male (subject 1, 2, 3 and 4) and three female (subject 5, 6 and 7) volunteers (n = 7) with ages ranging from 21 to 50, mean age (M) of 32.8 and standard deviation (SD) of 12.02, and academic backgrounds from a 2nd-year college level to a Ph.D. level participated in the present study. They were right-handed with a mean laterality quotient (L.Q.) of +77 and a mean decile of R.5 as assessed by the Edinburgh Inventory[38] and healthy native Japanese speakers with no history of neurological disease. The subjects received visual corrections prior to the experiments.

They started to learn English as a second language in school at the age of twelve and none had lived in an English-speaking country for more than one year. All subjects gave informed consent before MRI scanning and MEG measurement. The experiments were performed under the approval of the institution (Communications Research Laboratory, Ministry of Posts and Telecommunications, Japan).

Paradigm design

Experiments were designed to detect dynamic cortical activations of the Japanese-English mental translation task (test) and Japanese word repetition task (control). Categorized and randomized stimuli were used in mental translation to investigate category influences. An additional noun-verb generation task was conducted for comparison to translation task.

Measurement Methods

MEG data were acquired using a whole-head MEG system (Biomagnetic Technologies Magnes 2500 WH) having 148 channels magnetometer DC-SQUID sensors. The MEG system is shown in Fig. 4.4. MR images for dipole overlay were acquired using a 1.5 T whole body MRI scanner (Siemens Magnetom Vision). Two hundred slices of the subjects' whole-head were acquired with TR 9.7 ms, TE 4 ms, flip angle 12°, matrix 256 x 256, FOV 256 mm, pixel size 1 mm, slice thickness 1 mm, distance factor 0, sagittal orientation.

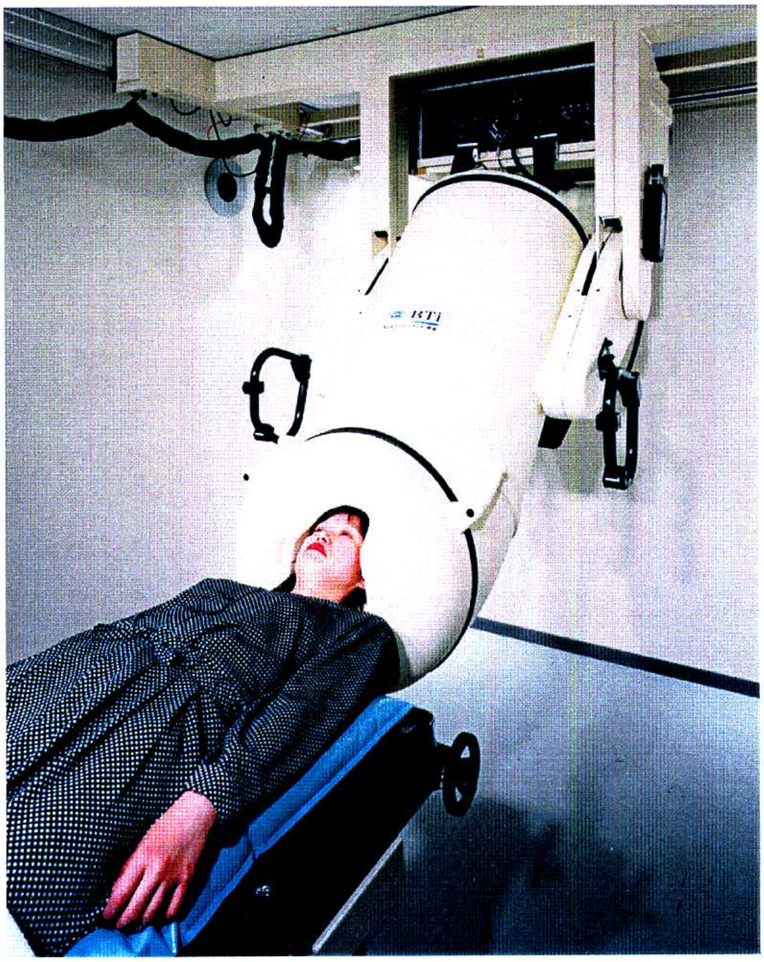


Fig. 4.4. A 148-channel MEG which was used in this study.

Stimuli and responses

During the experiments, the subjects saw 140 stimuli which were either Japanese Hiragana phonograms having two or three characters. Stimuli were generated by a personal computer (NEC) and visually presented via a projector (SHARP) onto a semi-transparent screen below a 0.4° x 04° fixation point with visual angles of either 3.2° or 4.8° horizontally and 1.6° vertically. The brightness of the stimuli and background were 320 and 2 cd/m^2, respectively. Stimuli were presented at a 1 s duration and a random change of interstimulus interval (ISI) between 1.5 and 2.5 s. Subjects in the supine positions viewed stimuli through a semi-transparent screen. Timing diagram of stimulus, trigger and reaction time is shown in Fig. 4.5.

The stimuli were familiar nouns consisting of two or three Hiragana characters and two or three syllables. Example of randomized translation, categorized translation, noun-verb generation and word repetition experiments are shown in Table 4.1.

The subjects were instructed to silently read and respond to the stimuli to avoid head movement. Reaction times were recorded simultaneously during MEG experiments for behavioral studies. A reaction button was pressed with the left index finger at the beginning of inner speech. Short practice sessions were given prior to the experiments.

EXPERIMENT	Stimulus 1	Response 1	Stimulus 2	Response 2
RANDOMIZED TRANSLATION	ねこ ("neko")	"cat" button-press	はこ ("hako")	"box" button-press
CATEGORIZED TRANSLATION	いぬ ("i-nu")	"dog" button-press	くま ("kuma")	"bear" button-press
NOUN-VERB GENERATION	ほん ("hon")	"yomu" button-press	みず ("mizu")	"nomu" button-press
WORD REPETITION	かべ ("kabe")	"kabe" button-press	やま ("yama")	"yama" button-press

Table. 4.1. Example of Randomized Translation, Categorized Translation, Noun-Verb Generatioin and Word Repetition Experiments.

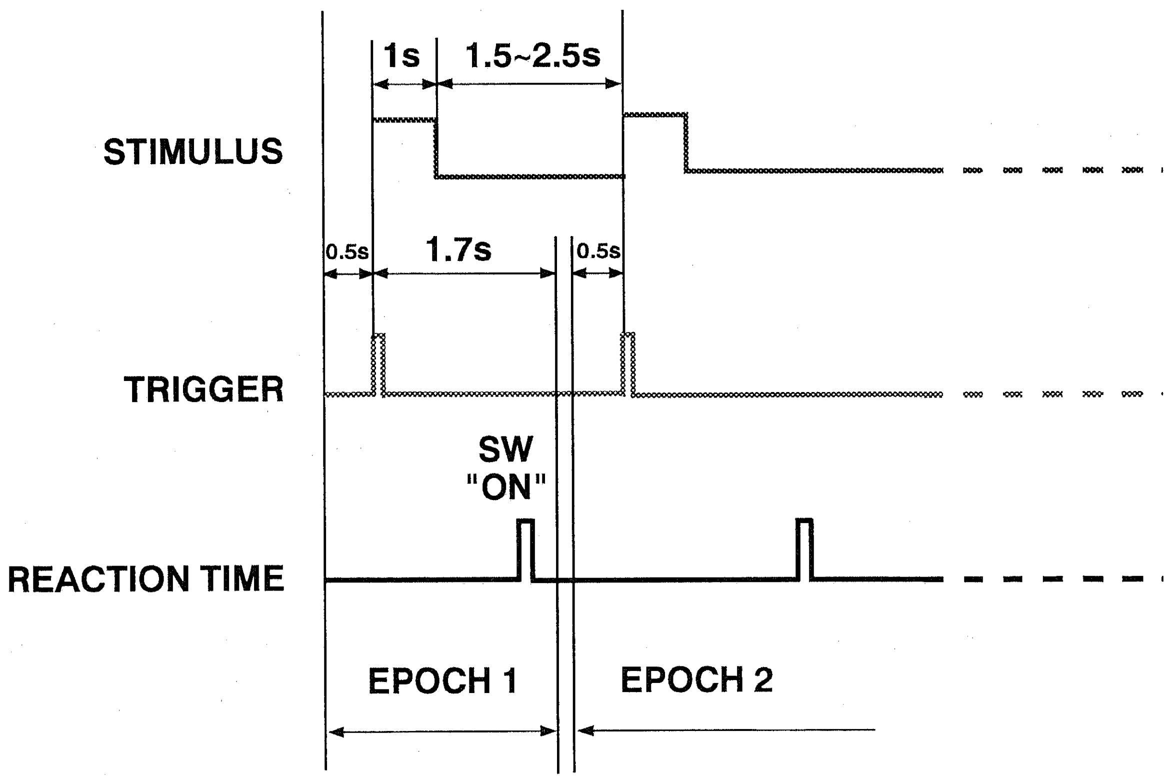


Fig. 4.5. Timing diagram of MEG experiment.

MR-Dipole registration

For a given subject, the following three markers are required to define the head frame *x, y, z* coordinate as shown in Fig. 4.6.:

(1) Nasion

(2) Left Preauricular (LPA)

(3) Right Preauricular (RPA).

Coordinate system used in the present study are defined as follows:

Origin: The origin is the midpoint between the LPA and RPA points.

The *x* axis: The positive *x* axis extends from the origin through the Nasion.

The *z* axis: The positive *z* axis extends from the origin through the top of the head such that it is perpendicular to the plane formed by the Nasion and the LPA points.

The *y* axis: The positive *y* axis extends from the origin through the left side of the head such that it is perpendicular to the *x* and *z* axes.

Registration of three markers into the subject's MR images were conducted by placing a vitamin capsule at Nasion and wearing ear plugs which contained oil inside for LPA and RPA prior to whole-head MR scanning. These markers appear in MR images indicating the Nasion, LPA and RPA of the subject which are used for MR-Dipole overlay in MEG system.

In each experimental session, before starting MEG measurement, the position of the subject's markers and head shape are obtained by a digitizer stylus pen. The head shape data are used for automatic calculation of a sphere used in dipole estimation and assisting MR overlay. The sphere have an origin which coincides with the center of the subject's head and surface curvature which fits the region of the subject's headshape. The markers are needed for individual registration of MR coordinate to the head frame *x, y, z* coordinate of the MEG system.

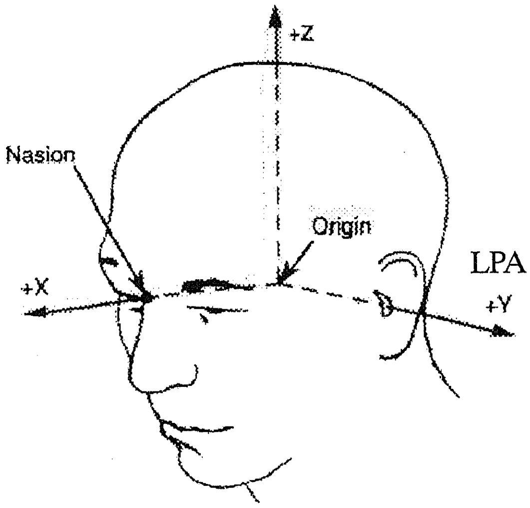


Fig.4.6. The head frame coordinate system.

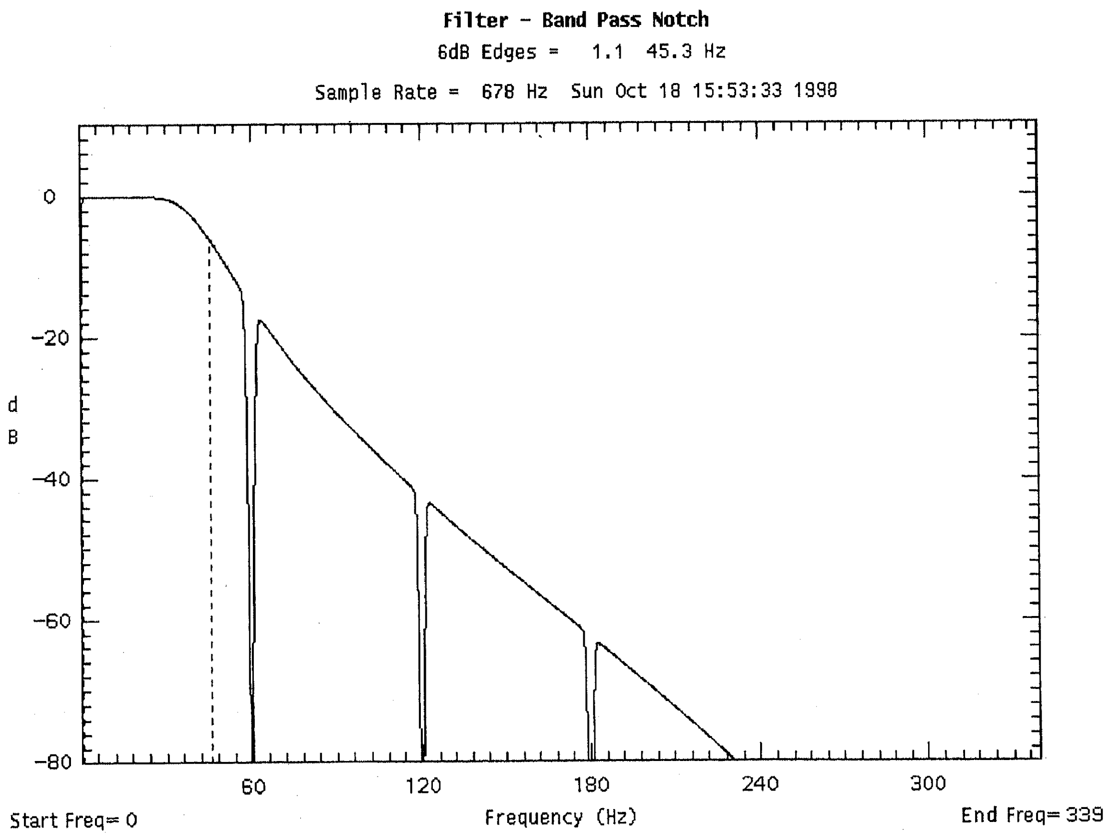


Fig. 4.7. Characteristics of digital filter using in MEG study.

Data acquisition and processing

MEG data were acquired simultaneously from 148-channel whole-head type DC-SQUID magnetometers which were housed in a magnetically shielded room (MSR). MSR (Type: AK-3B, fabricated by Tokin Co., Ltd.) was mounted on a Takenaka Active Microtremor System (TACMI) to eliminate environmental magnetic noises from low frequency vibration. Sampling frequency of data was 678.17 Hz with a bandwidth of 200 Hz.

One experimental session consisted of either three or four runs which are translation of visual randomized stimuli, translation of visual categorized stimuli, word repetition of visual stimuli and verb generation of visual stimuli. The orders of run were counter-balanced across subjects. One run consisted of 140 epochs having pretrigger duration of 0.5 second and epoch duration of 1.7 second.

The acquired data were averaged 140 times and filtered by a band pass filter of 1-40 Hz and notch filter of 60 Hz having characteristics as shown in Fig. 4.7.

Dipole estimation

In this present study, a least squares dipole fit, a single dipole fit which is an alogorithm for single diple fit from Biomagnetic Technologies, was used to estimate locations of dipoles based on the sphere model. The least squares fit iteratively refines the initial guess for the location of the dipole until it converges to a dipole that best fits the MEG measurement.

The recorded MEG measurements for a single instant of time are expressed by an array of numbers

$$(m_1, \ldots, m_N)$$

where m is the recorded MEG measurement and N is the number of channels in the magnetometer. If a specific dipole of location **r** and orientation **q** is selected, the neuromagnetic field is predicted by the forward equation as

$$(f_1(\mathbf{r},\mathbf{q}), \ldots, f_N(\mathbf{r},\mathbf{q})) \ .$$

The cost function is constructed by forming the sum of squares of the differences between the recorded and predicted field values as following:

$$C(\mathbf{r},\mathbf{q}) = (\mathrm{m}_1 - f_1(\mathbf{r},\mathbf{q}))^2 + \ldots + (\mathrm{m}_N - f_N(\mathbf{r},\mathbf{q}))^2. \tag{4.4}$$

The algorithm can be expressed as

$$\sum_{i=1}^{N} (\mathrm{m}_i - f_i(\mathbf{r},\mathbf{q}))^2 \rightarrow \min .$$

The iteration to minimize the cost function starts from a calculation of predicted field from the initial guess of the dipole. After converging of iteration which give the minimum value of the cost function, the final $(\hat{\mathbf{r}},\hat{\mathbf{q}})$ provide location and orientation of the estimated dipole.

Evaluation criteria

In the present study, the following criteria were used for evaluating of the equivalent current dipoles (ECD):

(1) Goodness of Fit > 0.9

(2) Confidence Regions < 14.2 cm^3

(3) Stationary > 7 ms

(4) 80 ms < Latency of Interest < RT

(5) Physiological and anatomical consistencies.

Goodness of Fit

The goodness of fit (g) is a parameter used to determine how well the observed measurements and the resulting dipole fit agree with the calculating model. Goodness of fit can be obtained by the following equation,

$$g = 1 - \frac{\sum_{i=1}^{N} \left(m_i - f_i(\hat{\mathbf{r}}, \hat{\mathbf{q}})\right)^2}{\sum_{i=1}^{N} m_i^2} \tag{4.5}$$

where g is the goodness of fit, N is the number of channels in the magnetometer, m is the recorded MEG measurements for a single instant of time and $\mathbf{r}$ and $\mathbf{q}$ are the location and orientation of calculated dipole, respectively.

Confidence Regions

Because a dipole fit in the presence of noise involves random variables, the dipole estimate itself is a random variable. Therefore, there is an inherent uncertainty in the dipole's location and orientation, and it is important to characterize this certainty. The confidence region contains the most probable set of points for the dipole's location. Confidence region of 95% is used which gives the intervals for each of *x, y, z* components of the dipole's location as following:

$$(\hat{x} - 1.96\,\sigma_x,\ \hat{x} + 1.96\,\sigma_x)$$

$$(\hat{y} - 1.96\,\sigma_y,\ \hat{y} + 1.96\,\sigma_y)$$

$$(\hat{z} - 1.96\,\sigma_z,\ \hat{z} + 1.96\,\sigma_z)$$

where $\hat{x}$, $\hat{y}$, $\hat{z}$ are the location of an estimated dipole and $\sigma_x, \sigma_y, \sigma_z$ are the standard deviation of the error in the *x, y, z* coordinate, and 1.96 is a number determined from statistical tables.

Stationary

Stationary is defined in the present study as a time period in ms that the location of estimated dipoles do not change more than 1 cm in the *x, y, z* direction.

Latency

Since the visual characters were used in the present study, the minimum latency of interest was defined by approximate time for information from the on-set of stimulus to reach primary visual cortex (80 ms). On the other hand, the maximum latency of interest was limited to the mean reaction times (RT) for each experiments. Only dipoles that estimated from the latency between minimum and maximum limitations were considered to be meaningful.

Physiological and anatomical consistencies

Estimated dipoles were rejected based on the fundamentals of physiological and anatomical consistencies. The major rejections in the present study were as following:

(1) Dipole located in white matter of the brain
(2) Dipole located in Corpus callosum
(3) Dipole located in gyrus
(4) Dipole located in areas which are not related to visual or language function
(5) Dipole which overlapped many areas.

4.3 Results

Behavioral study

From the behavioral data, an analysis of variance (ANOVA) across 7 subjects using StatView Ver. 4.5 (Abacus Concepts, Inc.) indicated: (1) significant differences (p = 0.0004) between Japanese-English categorized translation (CAT) and randomized translation (RAN) (2) significant differences ($p < 0.0001$) between categorized, randomized translation and word repetition with degree of freedom (df) = 6, $F(1,6)$ = 511.5 as shown in Fig. 4.8. The mean reaction time (RT) for the categorized translation task was 1,155 ms (SD = 446.7), 1084 ms (SD = 381) for the randomized translation and 576 ms (SD = 254) for the word repetition task.

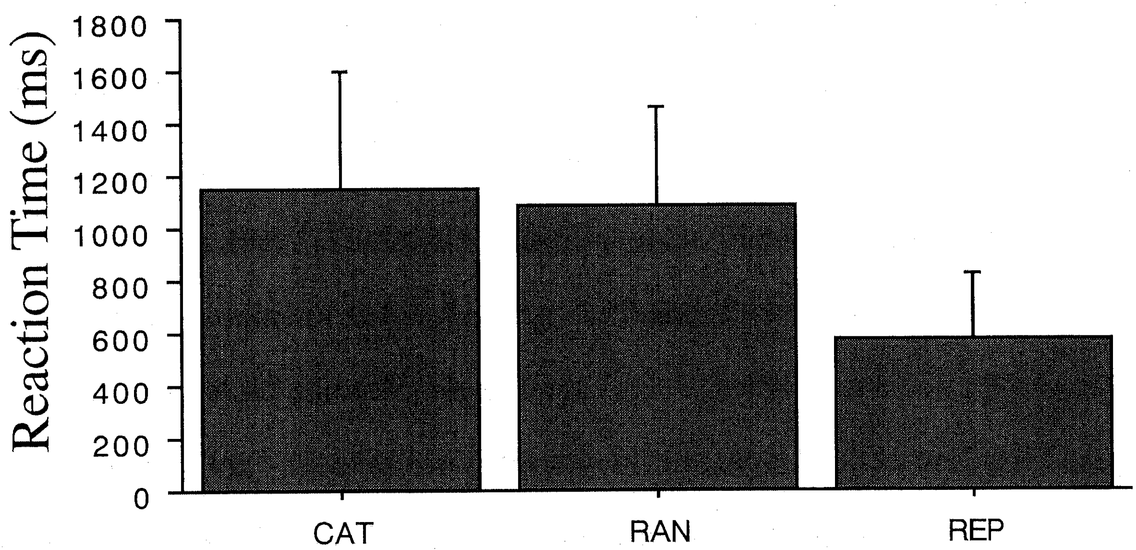


Fig. 4.8. Reaction times of Japanese word repetition (REP), Japanese-English randomized translation (RAN) and categorized translation (CAT).

MEG study

From Word Repetition Experiment, averaged 148-channel MEG signals are shown in Fig. 4.9 for subject 1a, 1b and 2, Fig. 4.10 for subject 3, 4 and 5 and Fig. 4.11 for subject 6 and 7. Estimated dipoles with latency bands are shown in Fig. 4.12 for subject 1a, Fig. 4.13 and 4.14 for subject 1b, Fig. 4.15 for subject 3, Fig. 4.16 for subject 4, Fig. 4.17 for subject 5, Fig. 4.18 for subject 6 and Fig. 4.19 for subject 7.

From Randomized Translation Experiment, averaged 148-channel MEG signals are shown in Fig. 4.20 for subject 1a, 1b and 2, Fig. 4.21 for subject 3, 4 and 5 and Fig. 4.22 for subject 6 and 7. Estimated dipoles with latency bands are shown in Fig. 4.23 for subject 1a, Fig. 4.24 and 4.25 for subject 1b, Fig. 4.26 for subject 2, Fig. 4.27 for subject 3, Fig. 4.28 for subject 4, Fig. 4.29 and 4.30 for subject 5, Fig. 4.31 for subject 6 and Fig. 4.32 for subject 7.

From Categorized Translation Experiment, average 148-channel MEG signals are shown in Fig. 4.33 for subject 1a, 1b and 2, Fig. 4.34 for subject 3, 4 and 5 and Fig. 4.35 for subject 6 and 7. Estimated dipoles with latency bands are shown in Fig. 4.36 for subject 1a, Fig. 4.37 and 4.38 for subject 1b, Fig. 4.39 for subject 2, Fig. 4.40 for subject 3, Fig. 4.41 for subject 4, Fig. 4.42 and 4.43 for subject 5, Fig. 4.44 for subject 6 and Fig. 4.45 and 4.46 for subject 7.

From Noun-Verb Generation Experiment, average 148-channel MEG signals are shown in Fig. 4.47 for subject 1b, 2 and 5. Estimated dipoles with latency bands are shown in Fig. 4.48 and Fig. 4.49 for subject 1b, Fig. 4.50 for subject 2 and Fig. 4.51 and 4.52 for subject 5.

Dynamic activations in MEG word repetition, randomized translation, categorized translation and verb generation are summarized in Fig. 4.53, 4.54, 4.55 and 4.56, respectively, where dipoles with periods of latencies are projected onto the simplified schematic human brain in lateral and medial views.

Distributions of estimated dipoles in the word repetition experiment indicated extensive activations in the right parieto-occipital sulcus (RPOS) at 135-253 ms, left collateral sulcus (LCOS) at 138-176 ms and bilateral posterior cingulate sulcus (PCIS) at 150-409 ms.

Randomized translation experiment showed similar extensive activations to word repetition experiment in RPOS and LCOS at 144-266 ms and PCIS at 150-623 ms with additional extensive activations in the left superior temporal sulcus (LSTS) at 213-656 ms and the left posterior lateral sulcus (LPLAS) at 213-656 ms.

Categorized translation experiment also demonstrated similar extensive activations to randomized translation experiment in RPOS at 147-169 ms, LCOS at 154-243 ms, PCIS at 154-577 ms, LSTS at 274-694 ms and LPLAS at 356-436 ms with an additional extensive activation in the right superior temporal sulcus (RSTS) at 228-383 ms.

Activations of noun-verb generation experiment were observed in RPOS at 154-166, LCOS at 238-249 ms, PCIS at 154-605 ms with additional extensive activation in LSTS at 257-456 ms. Except LSTS, activated areas were very similar to activation of word repetition experiment.

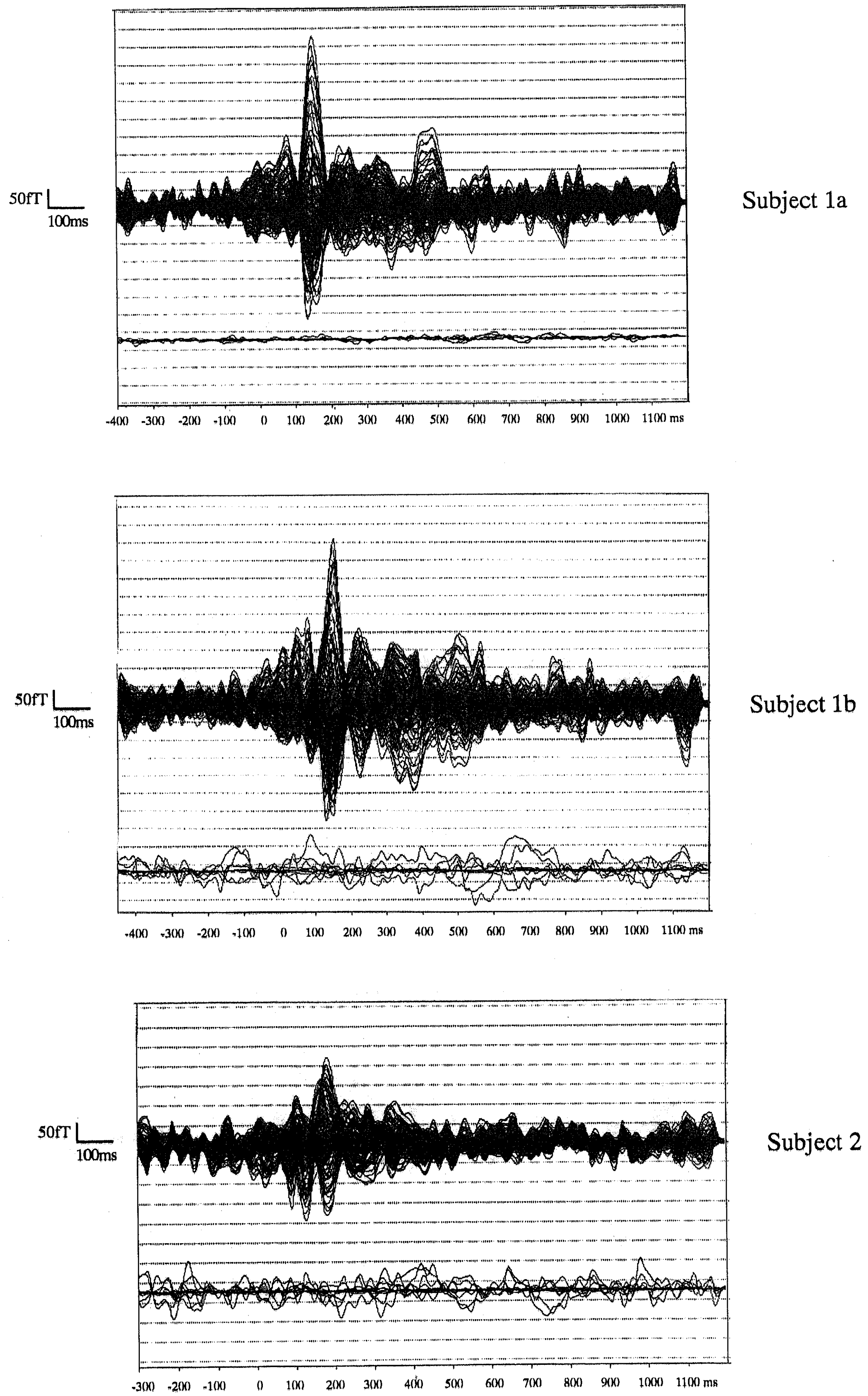


Fig. 4.9. MEG signal of subject 1a, 1b and 2 in Word Repetition.

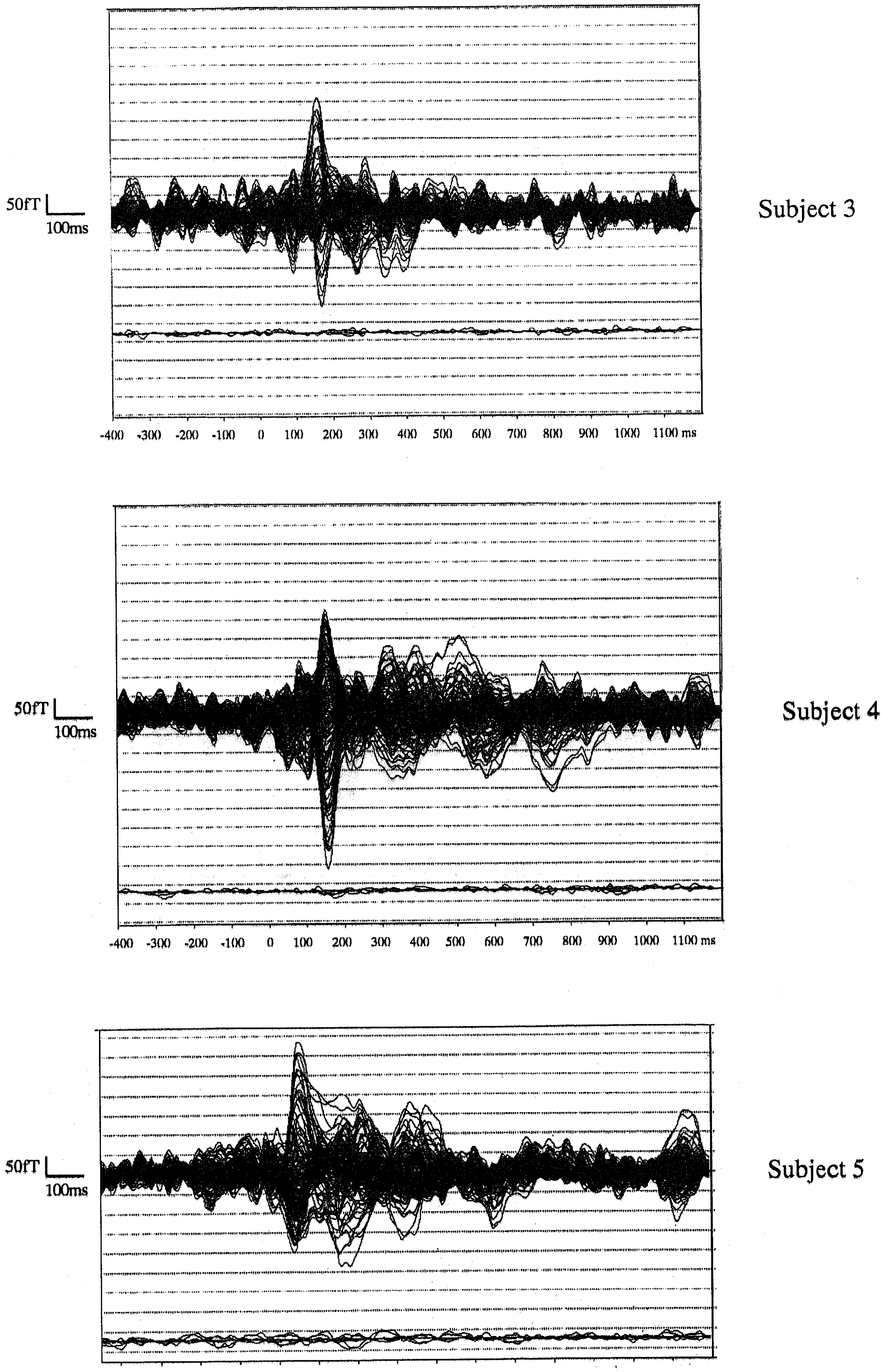


Fig. 4.10. MEG signal of subject 3, 4 and 5 in Word Repetition.

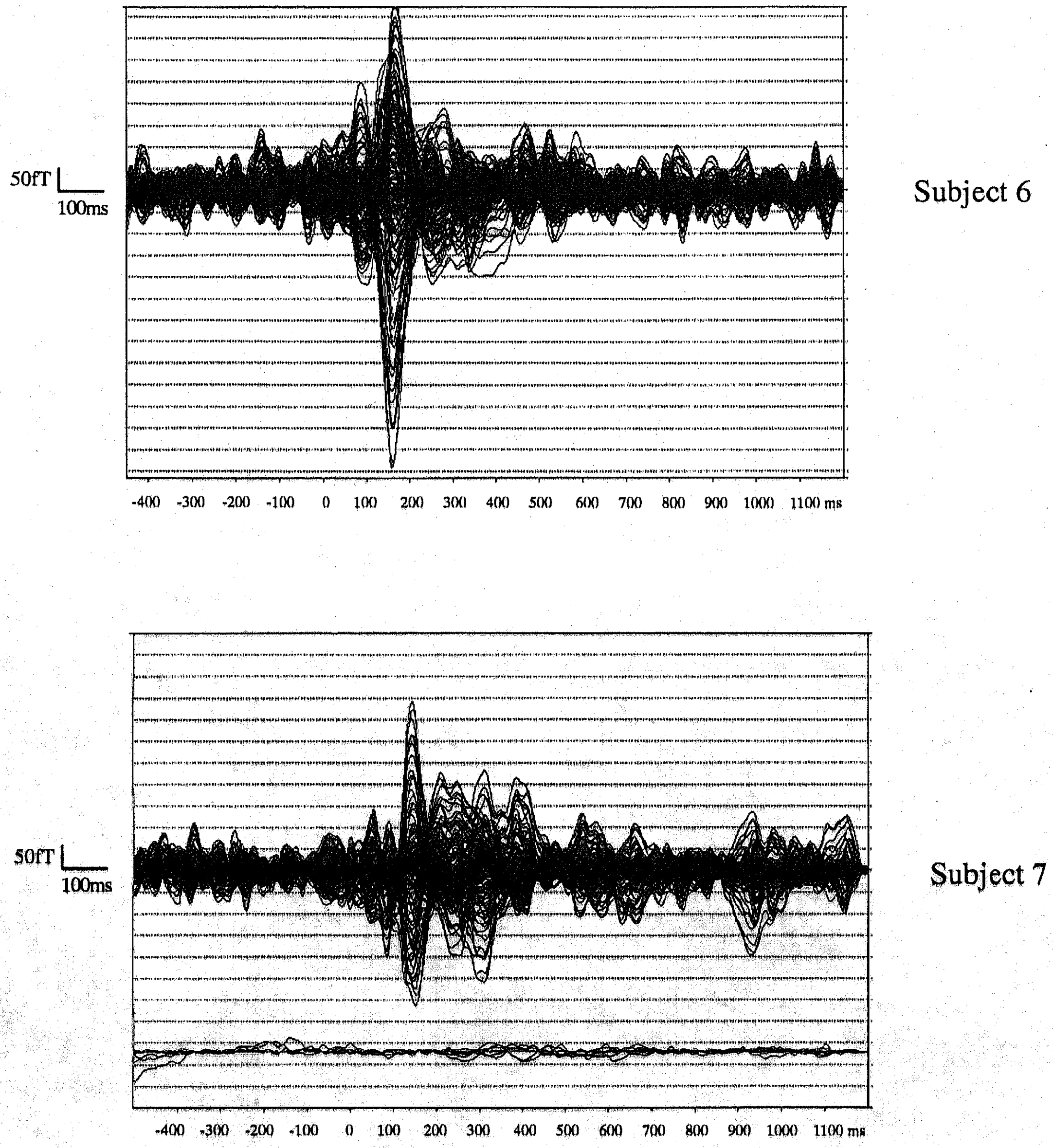


Fig. 4.11. MEG signal of subject 6 and 7 in Word Repetition.

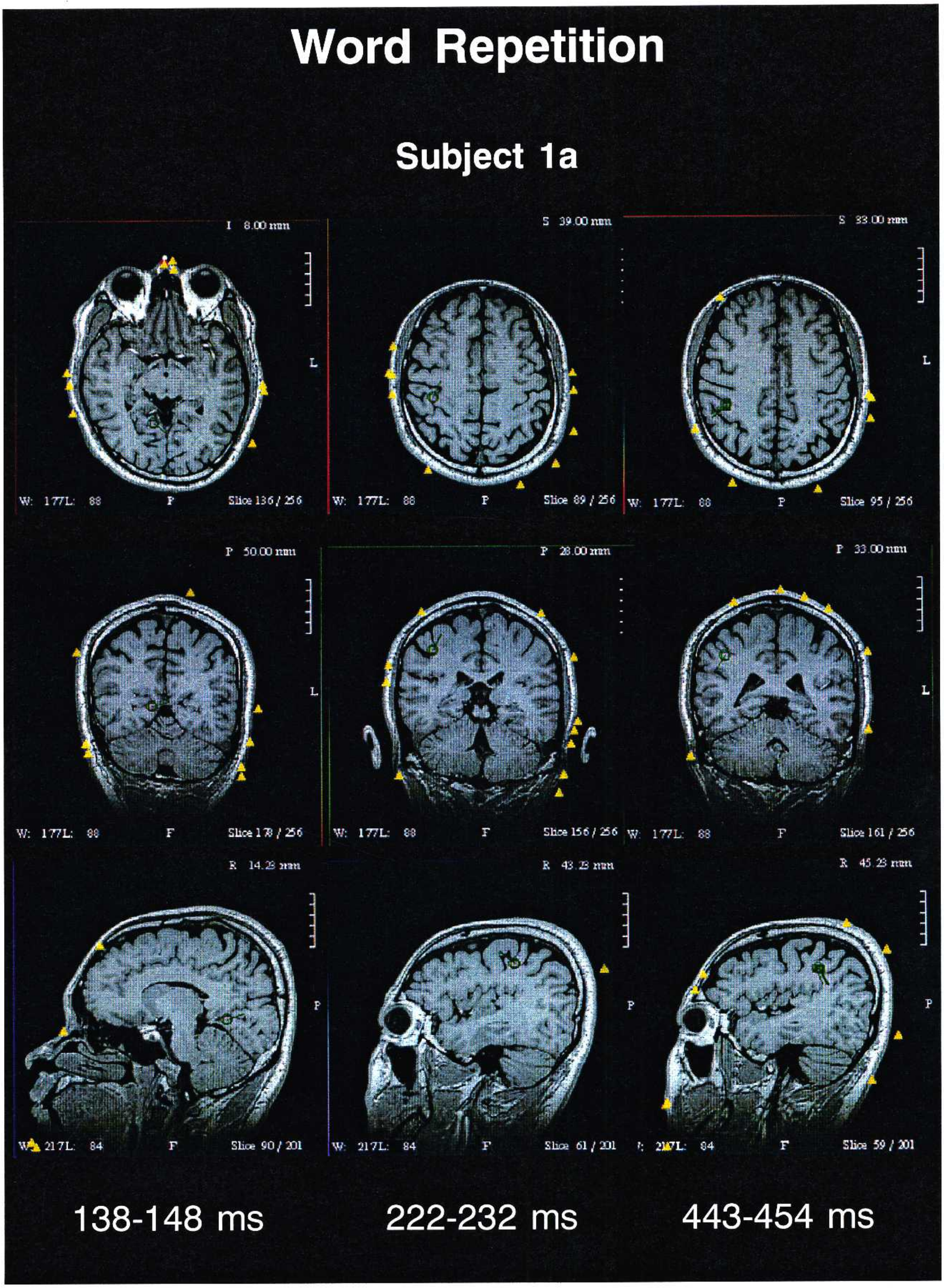


Fig. 4.12. Dipoles overlay on MR image of subject 1a in Word Repetition.

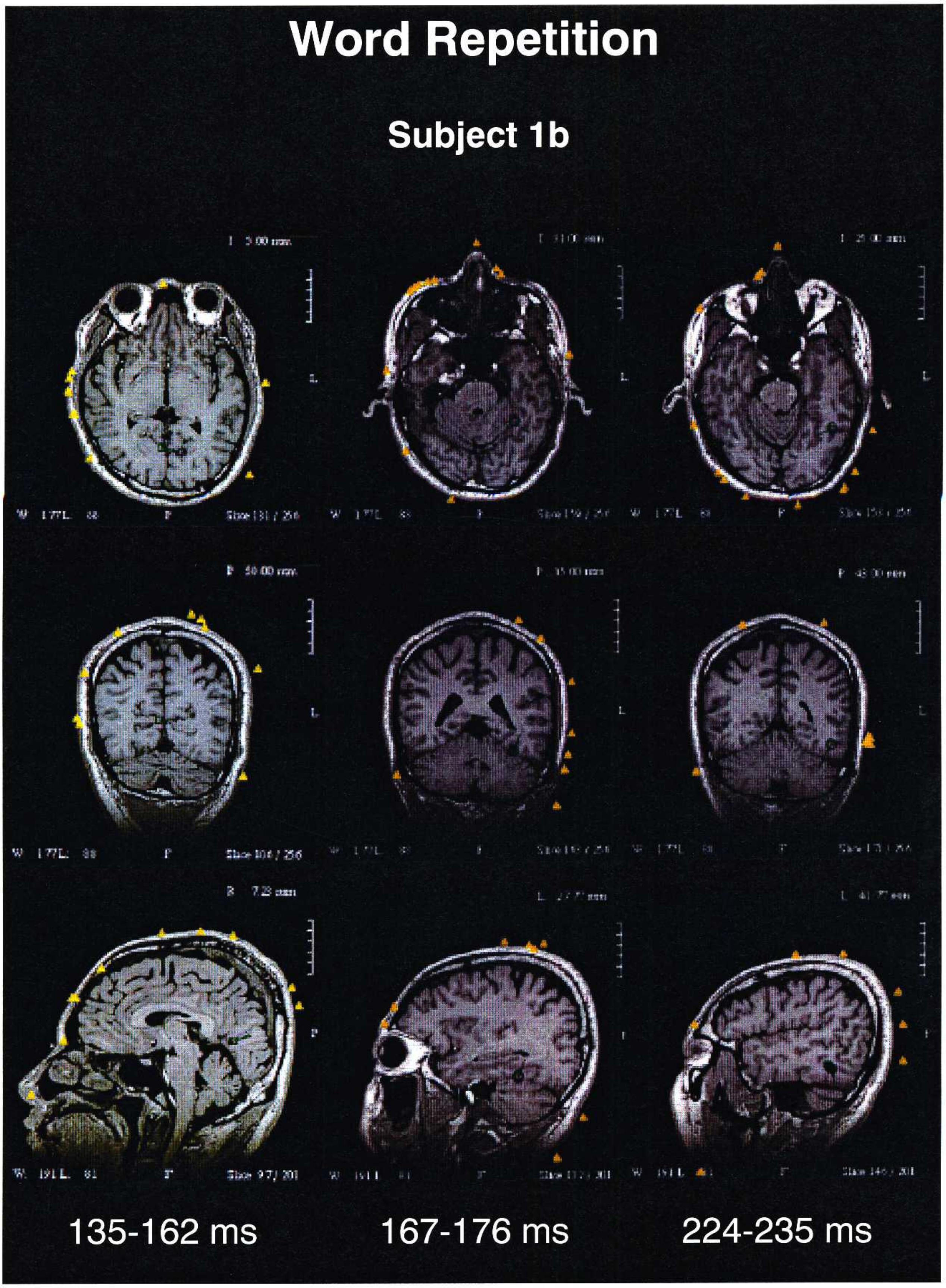


Fig. 4.13. Dipoles overlay on MR image of subject 1b in Word Repetition.

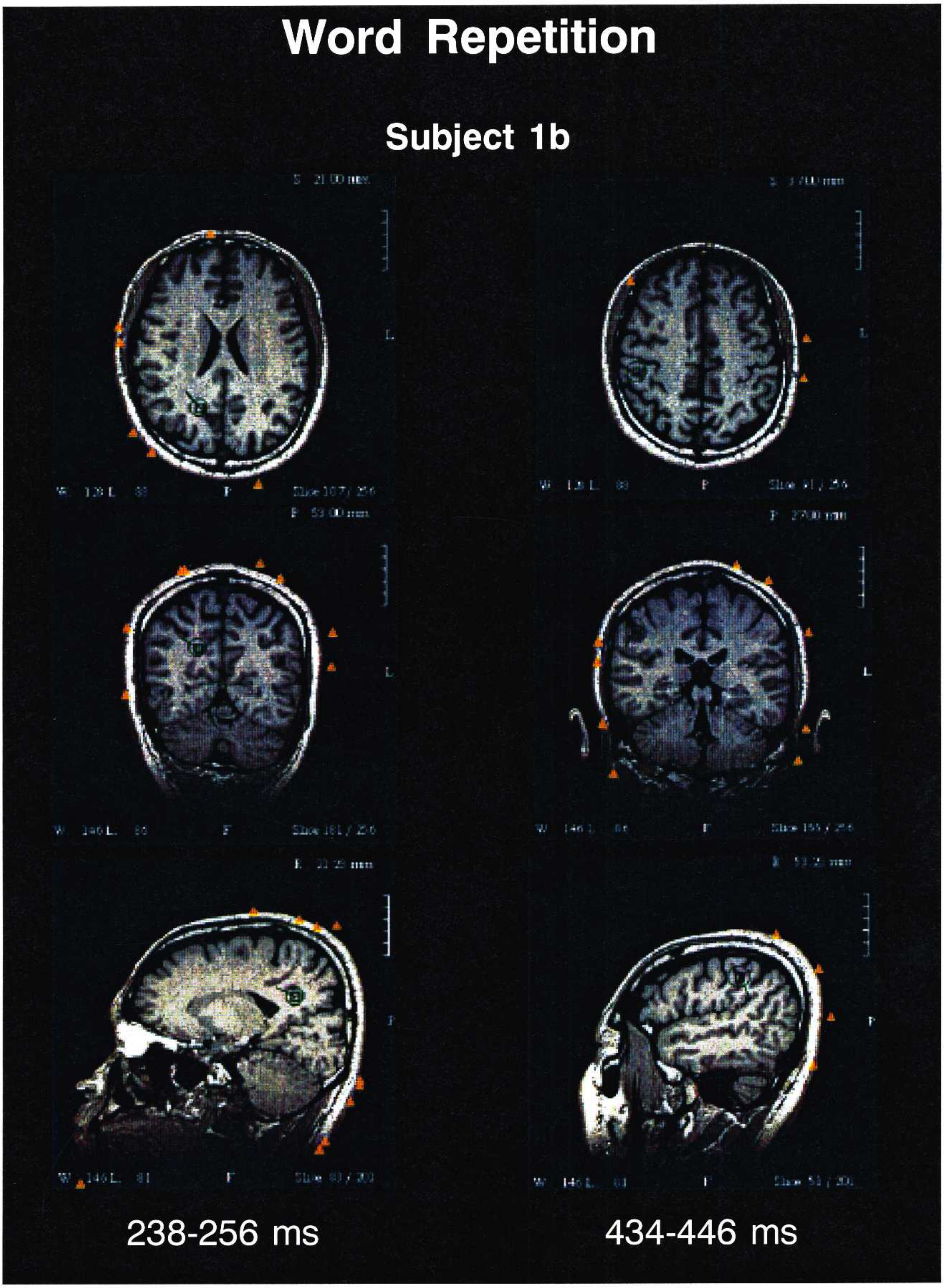


Fig. 4.14. Dipoles overlay on MR image of subject 1b in Word Repetition.

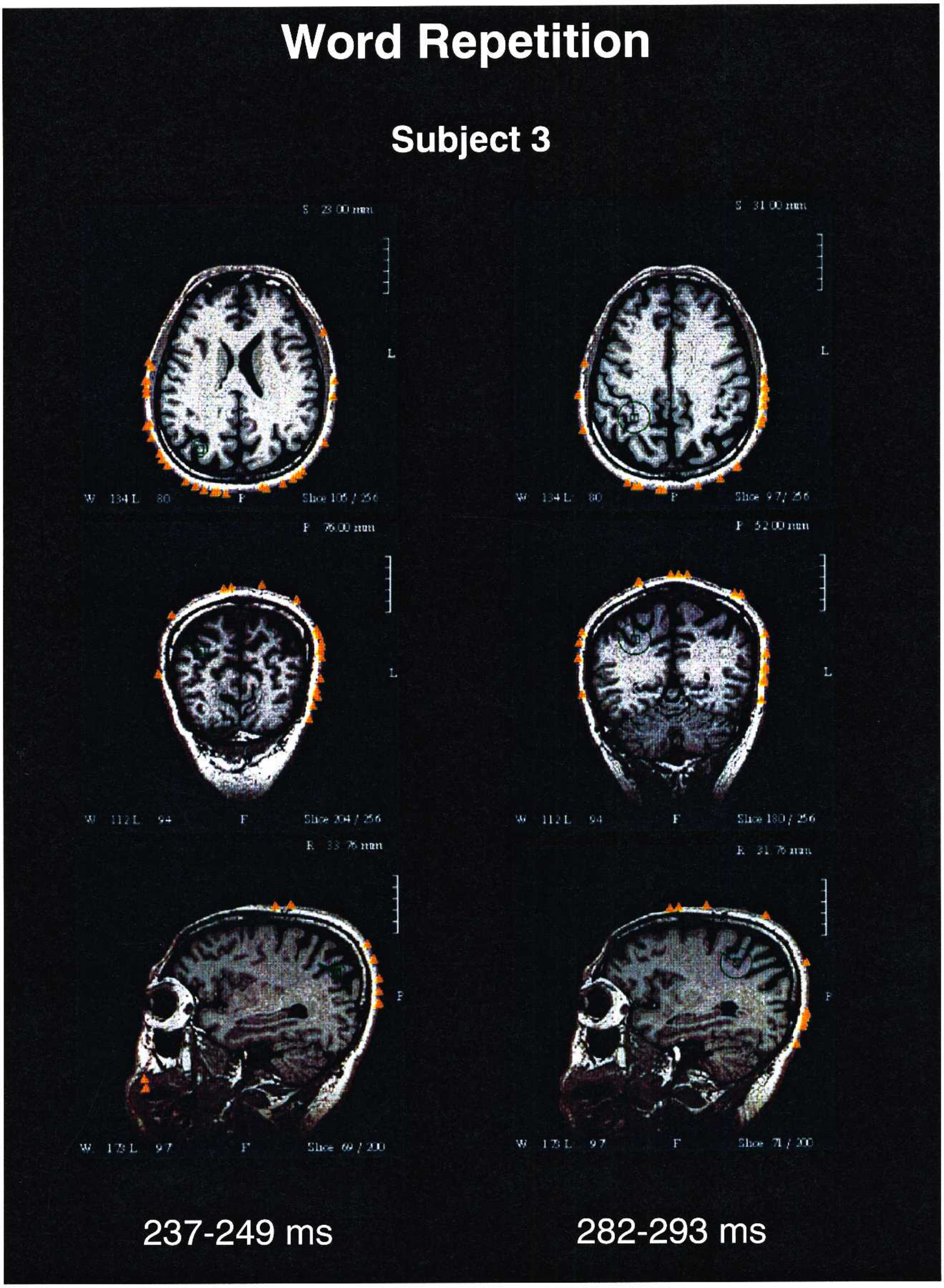


Fig. 4.15. Dipoles overlay on MR image of subject 3 in Word Repetition.

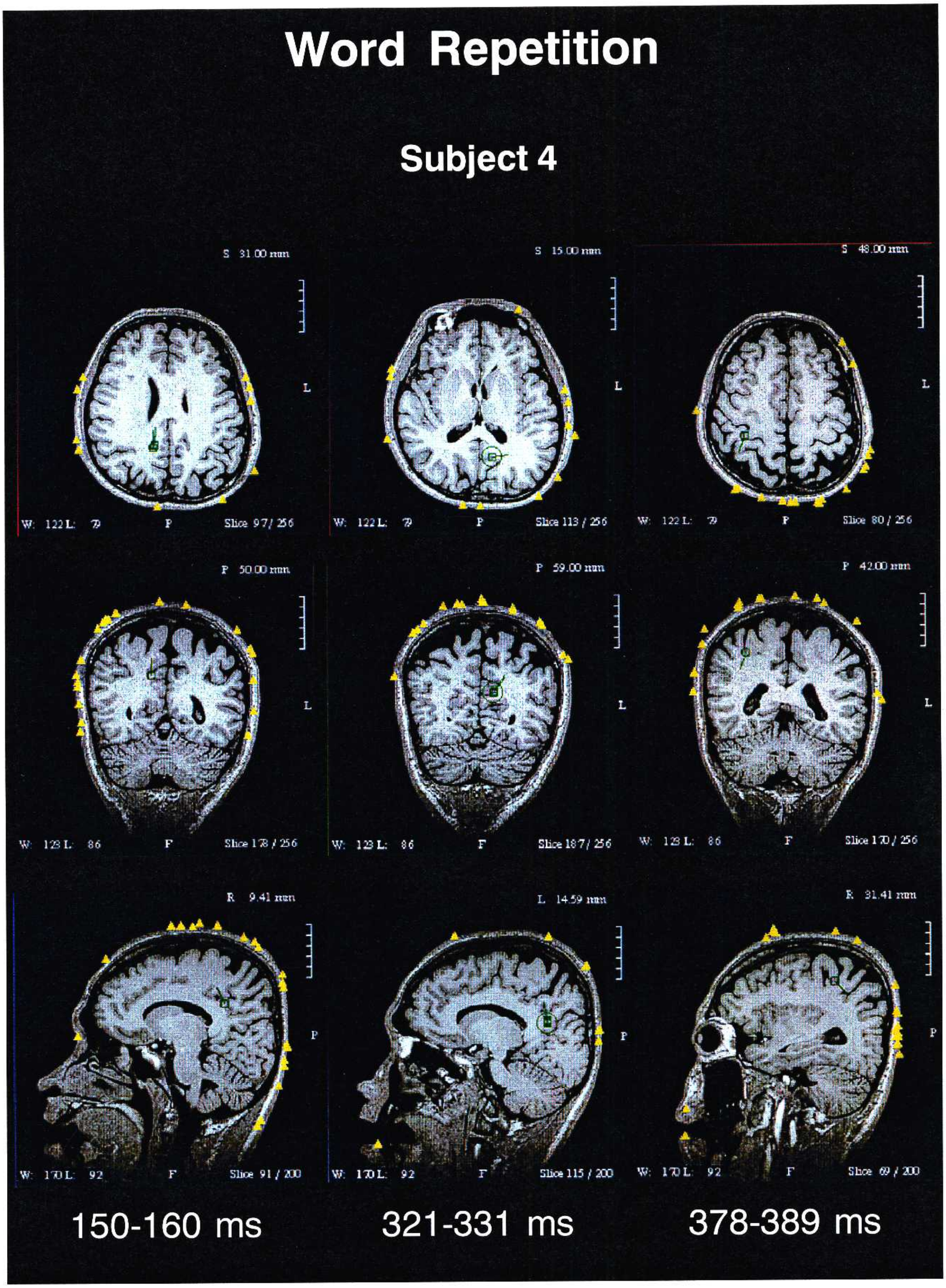


Fig. 4.16. Dipoles overlay on MR image of subject 4 in Word Repetition.

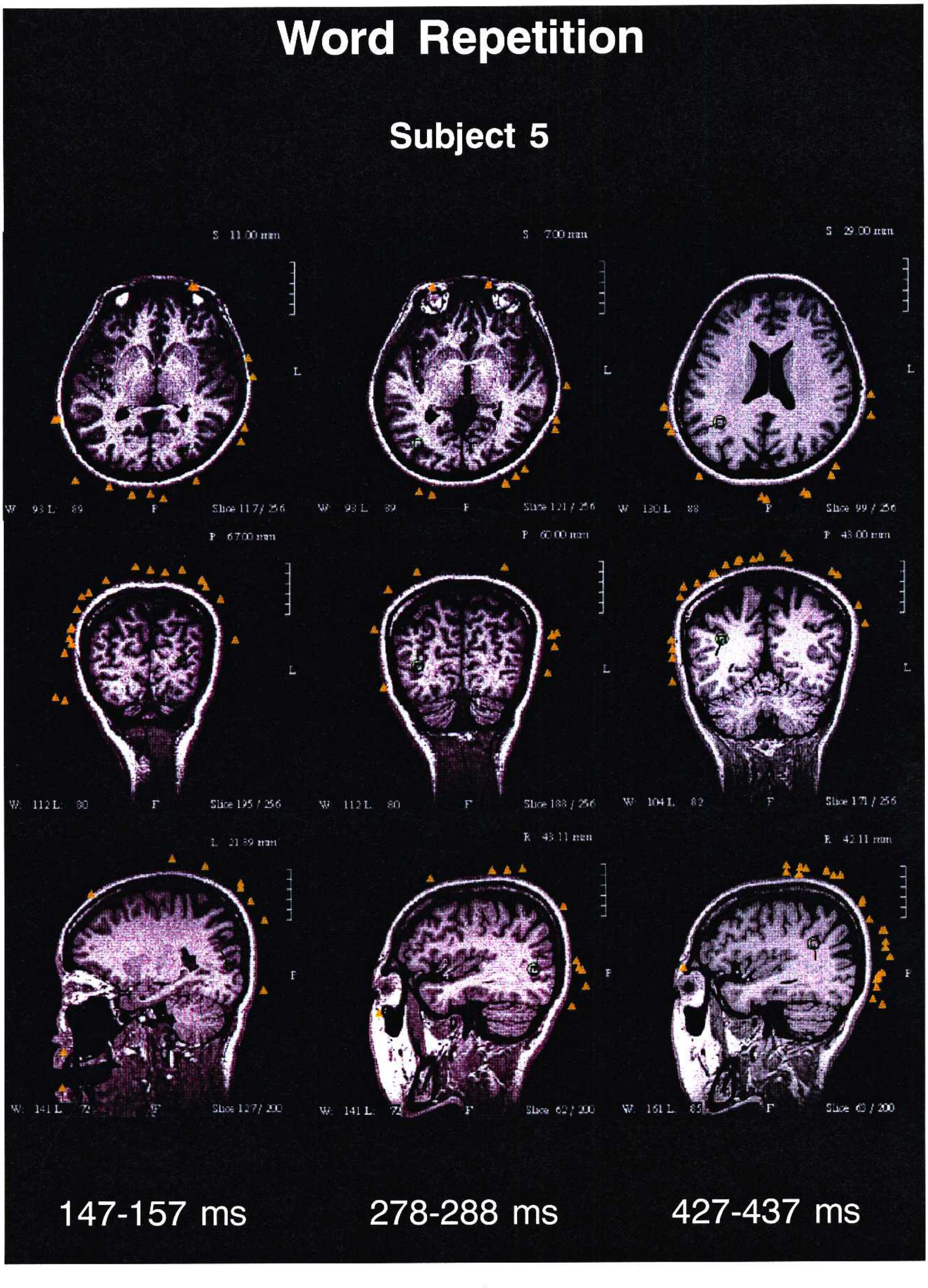


Fig. 4.17. Dipoles overlay on MR image of subject 5 in Word Repetition.

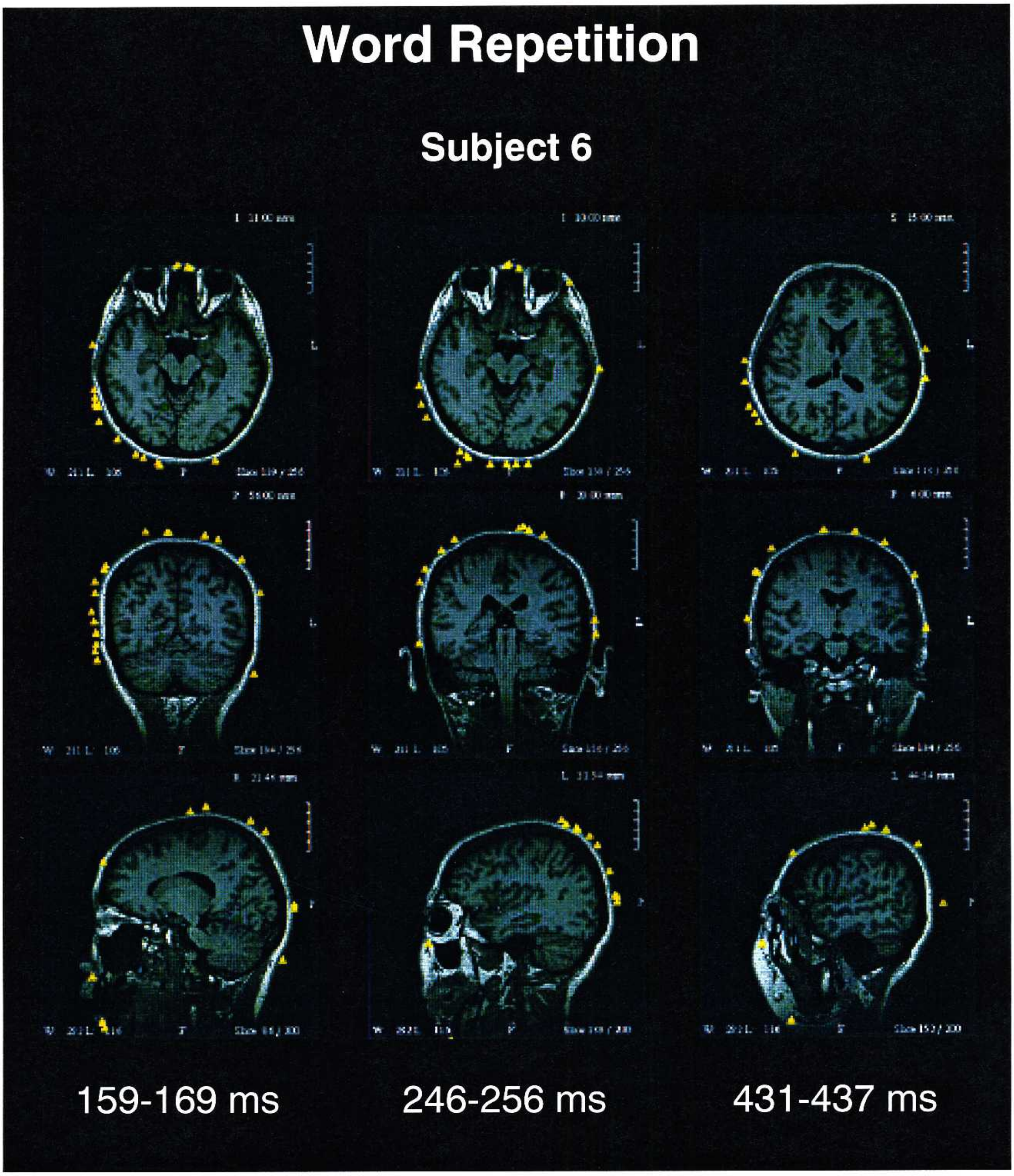


Fig. 4.18. Dipoles overlay on MR image of subject 6 in Word Repetition.

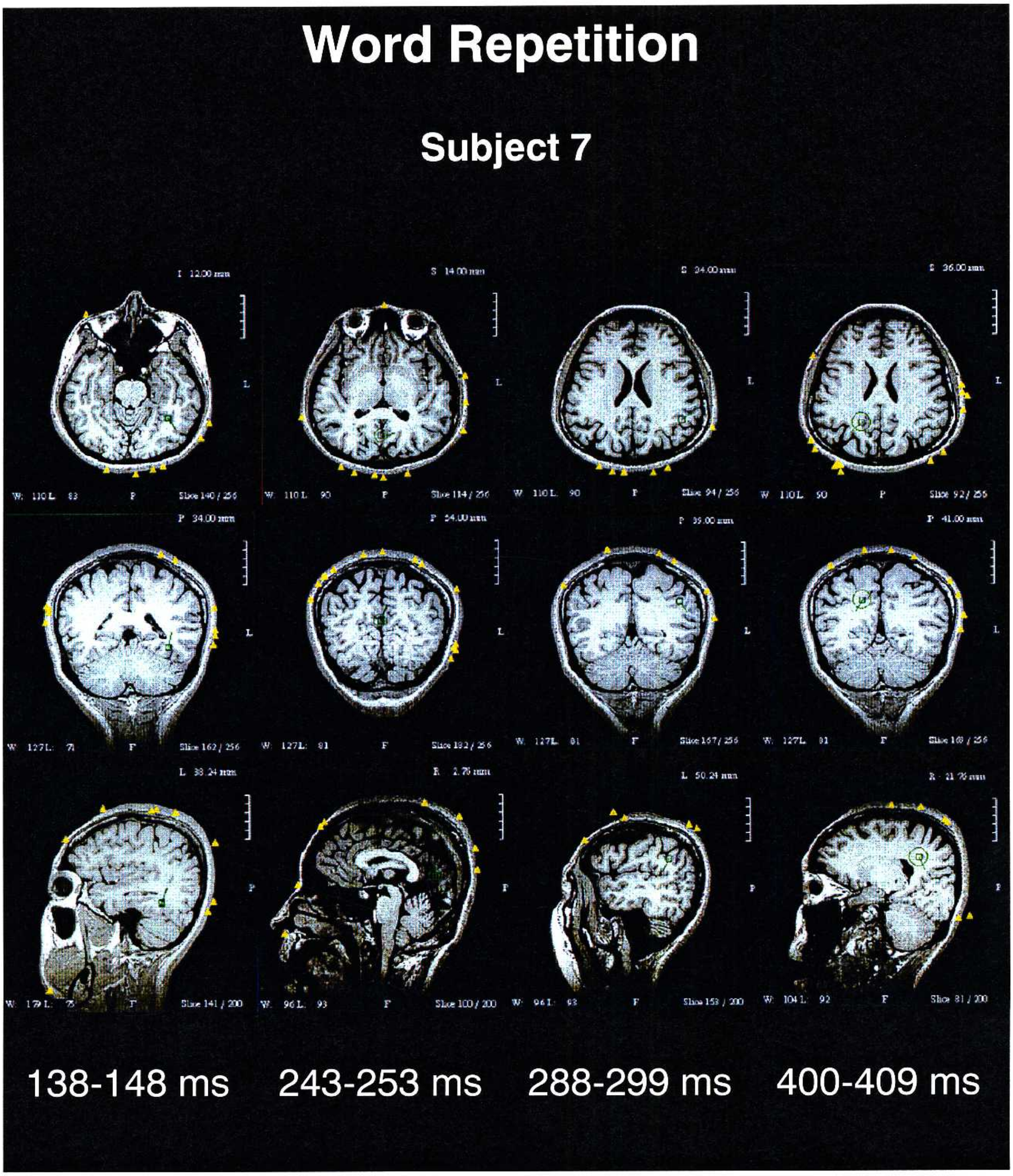


Fig. 4.19. Dipoles overlay on MR image of subject 7 in Word Repetition.

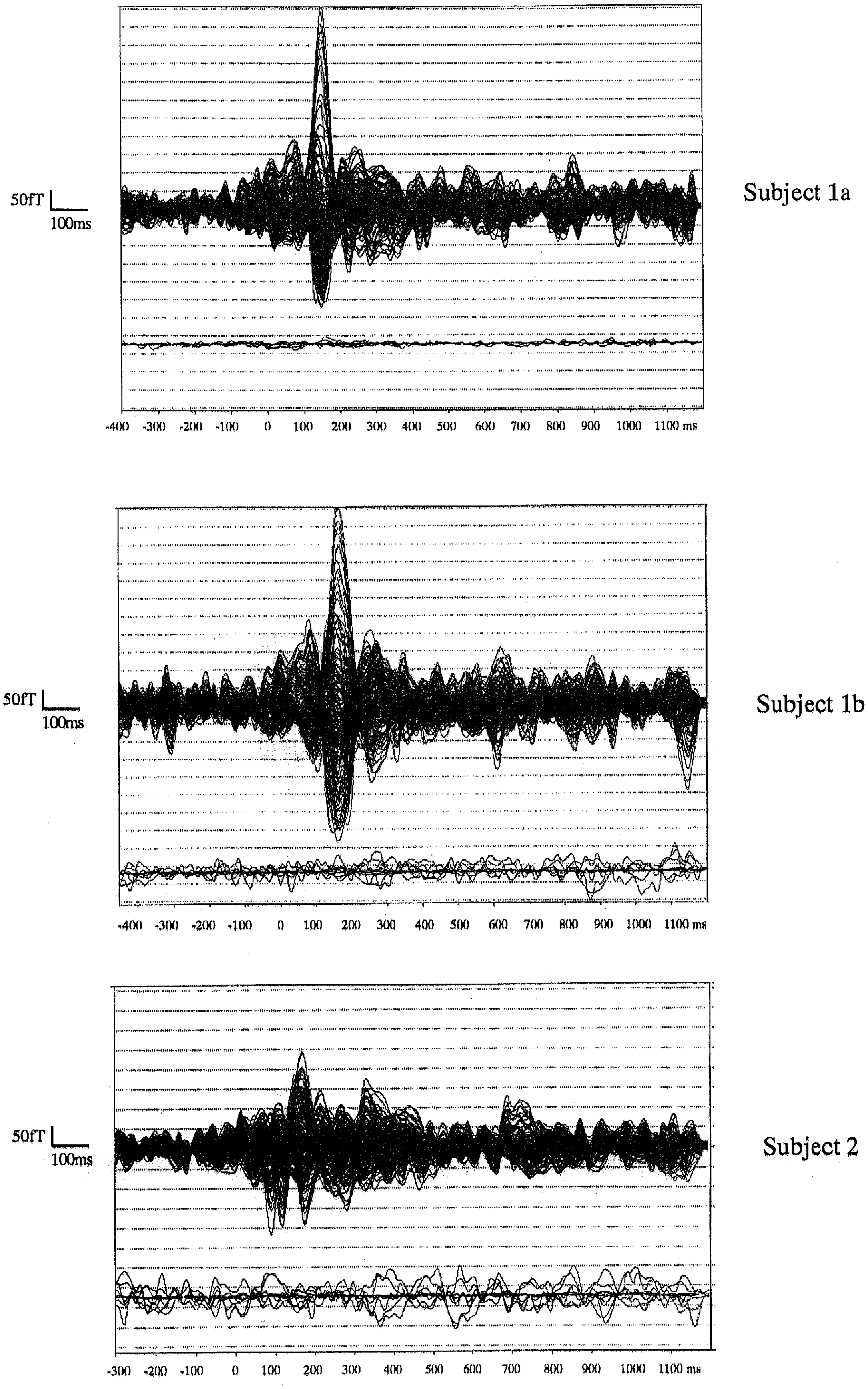


Fig. 4.20. MEG signal of subject 1a, 1b and 2 in Randomized Translation.

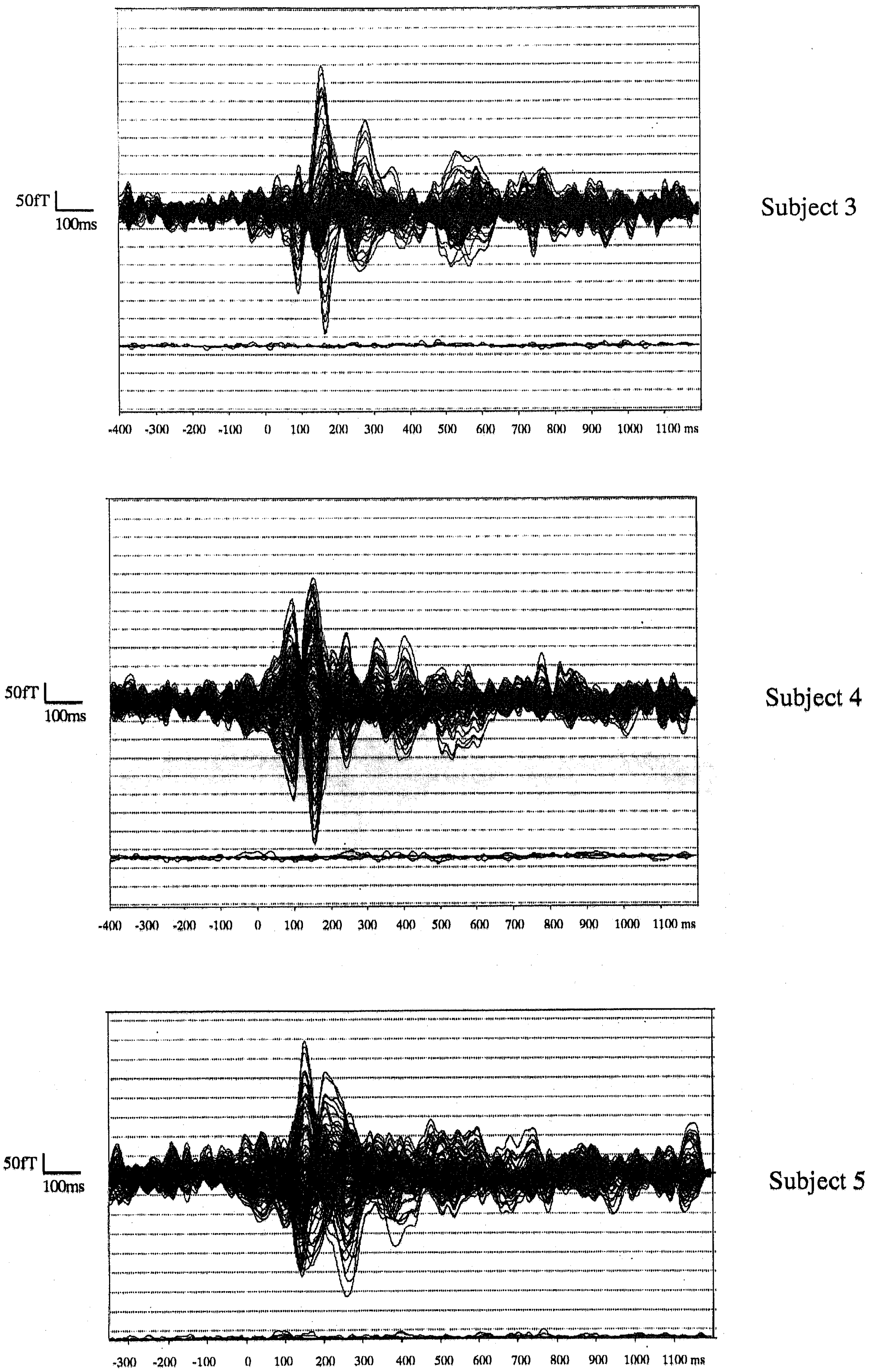
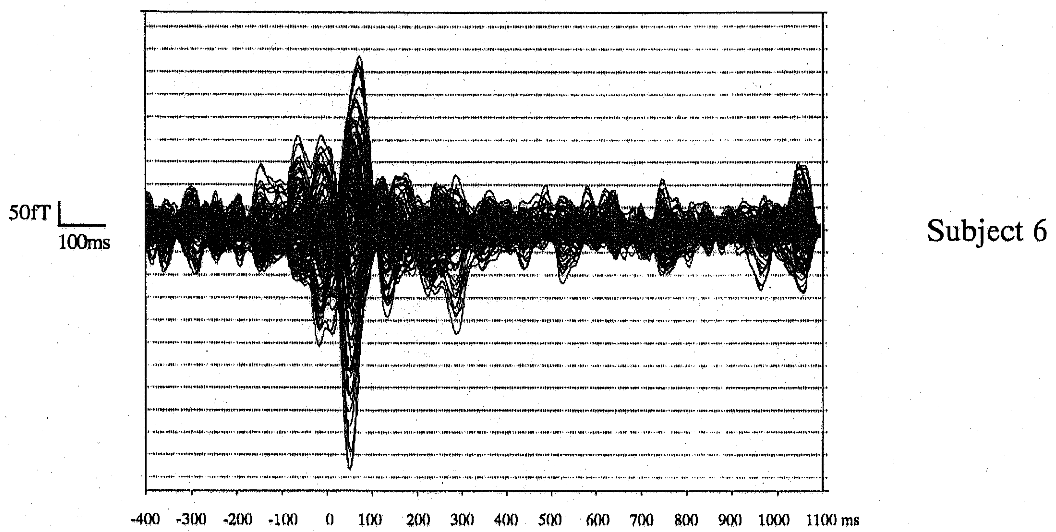


Fig. 4.21. MEG signal of subject 3, 4 and 5 in Randomized Translation.



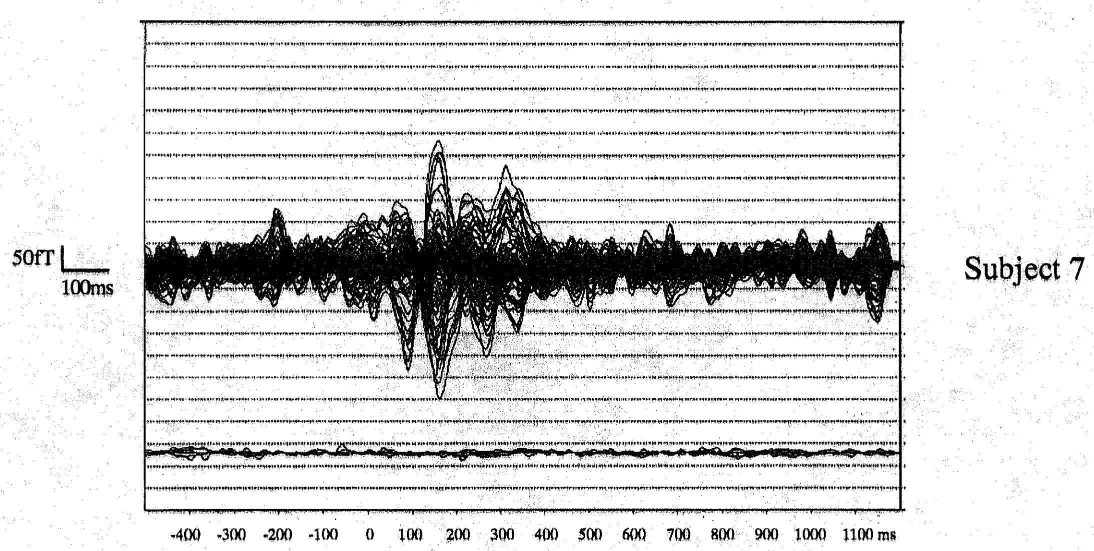


Fig. 4.22. MEG signal of subject 6 and 7 in Randomized Translation.

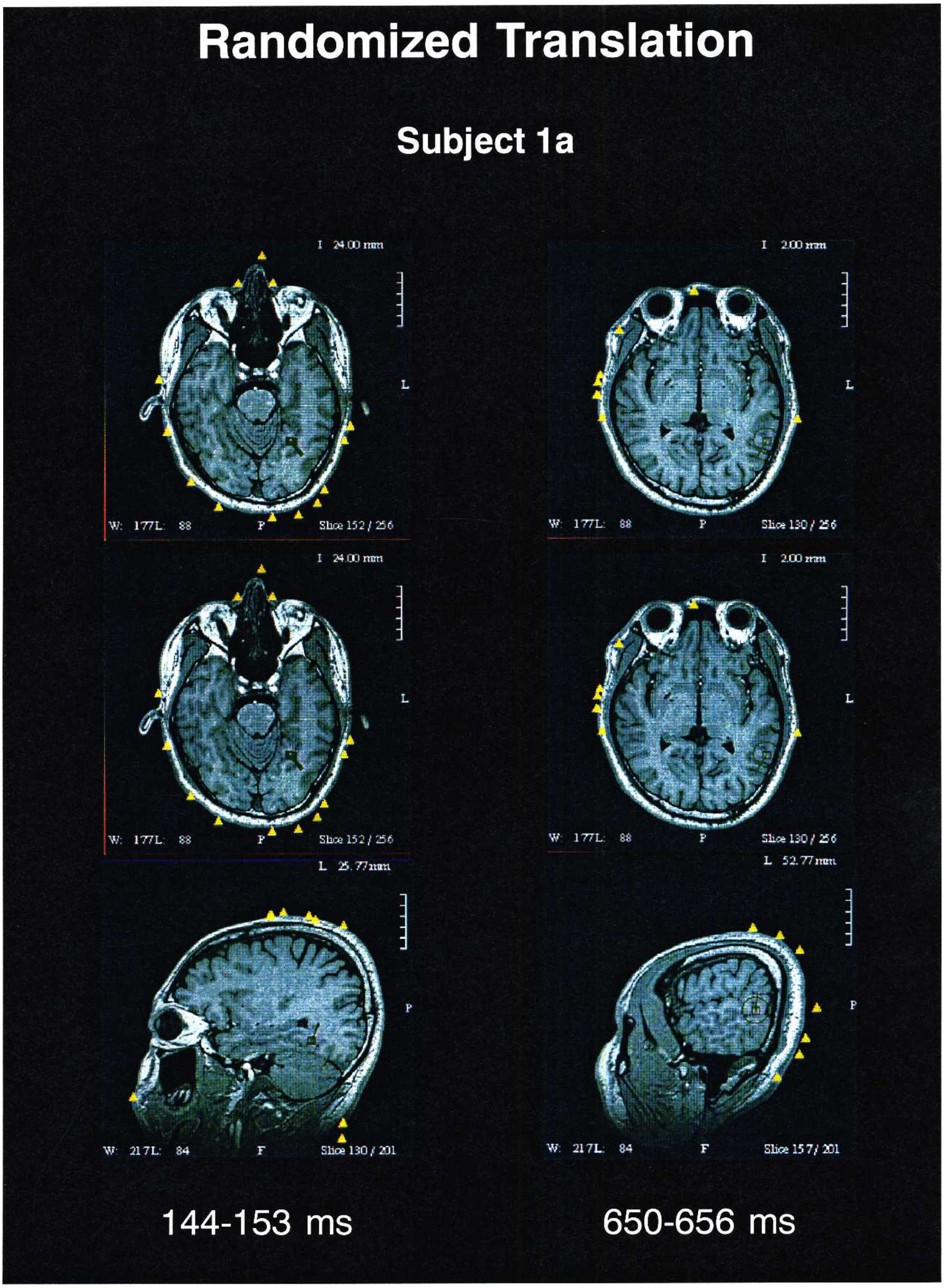


Fig. 4.23. Dipoles overlay on MR image of subject 1a in Randomized Translation.

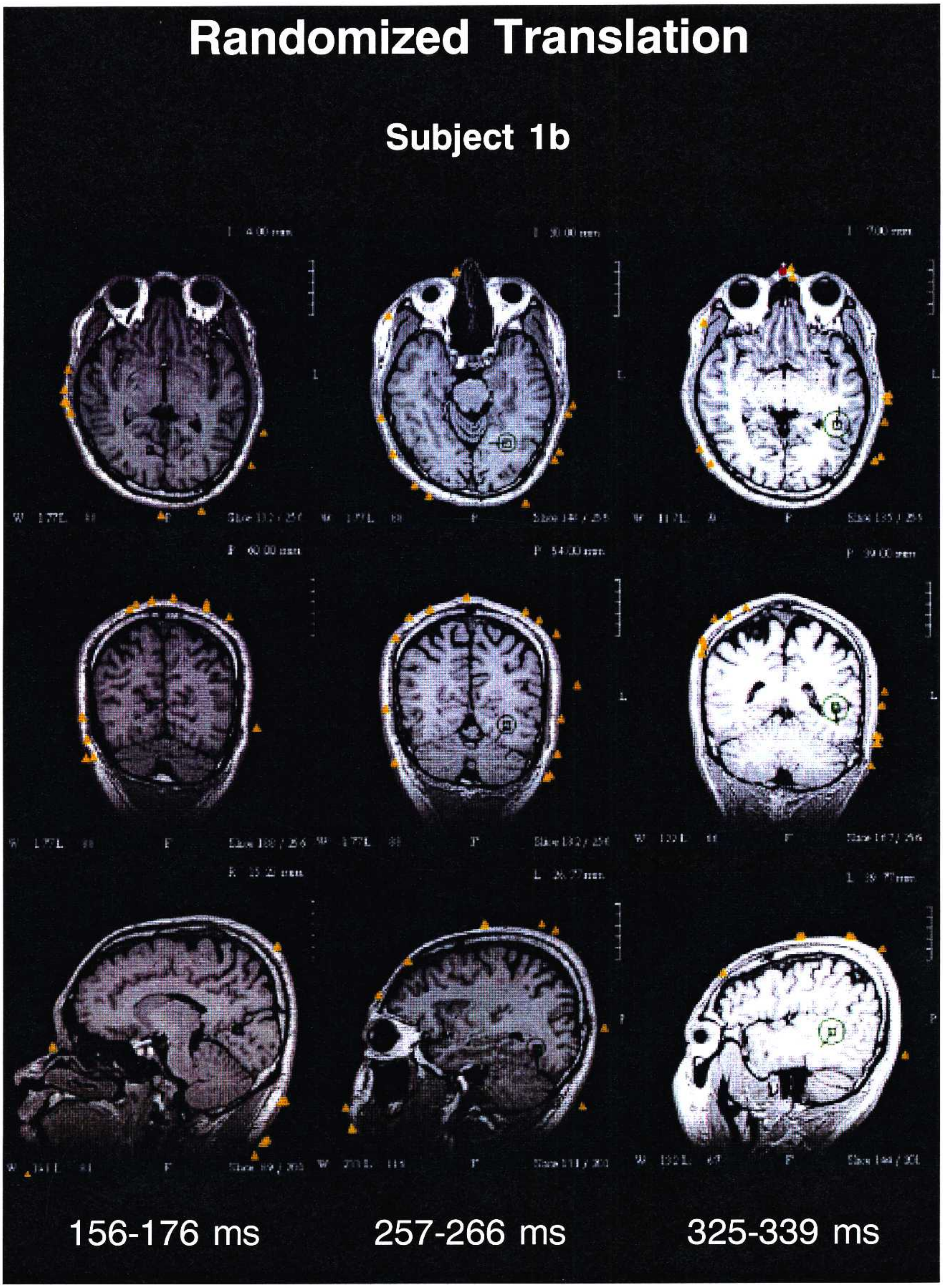


Fig. 4.24. Dipoles overlay on MR image of subject 1b in Randomized Translation.

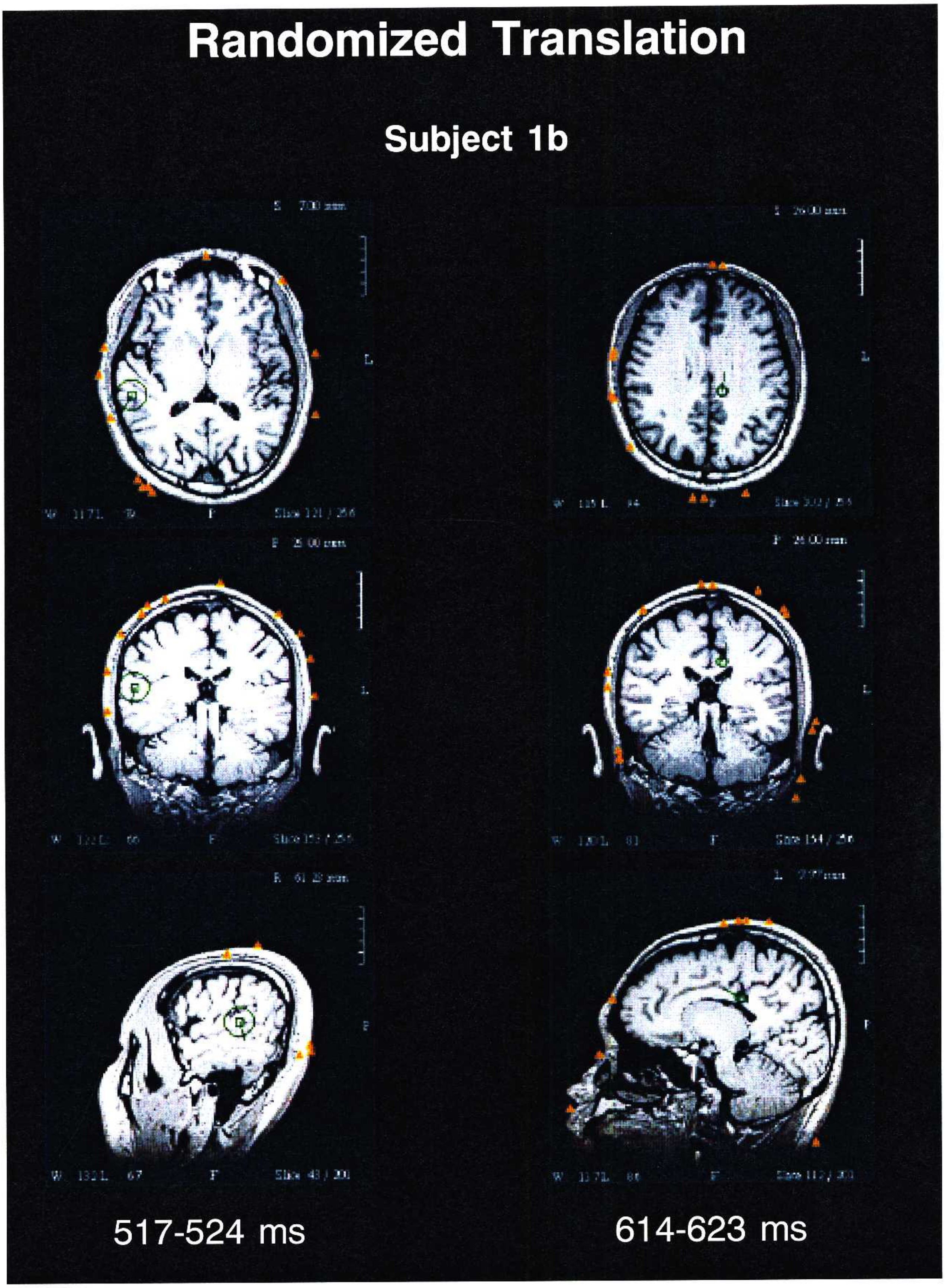


Fig. 4.25. Dipoles overlay on MR image of subject 1b in Randomized Translation.

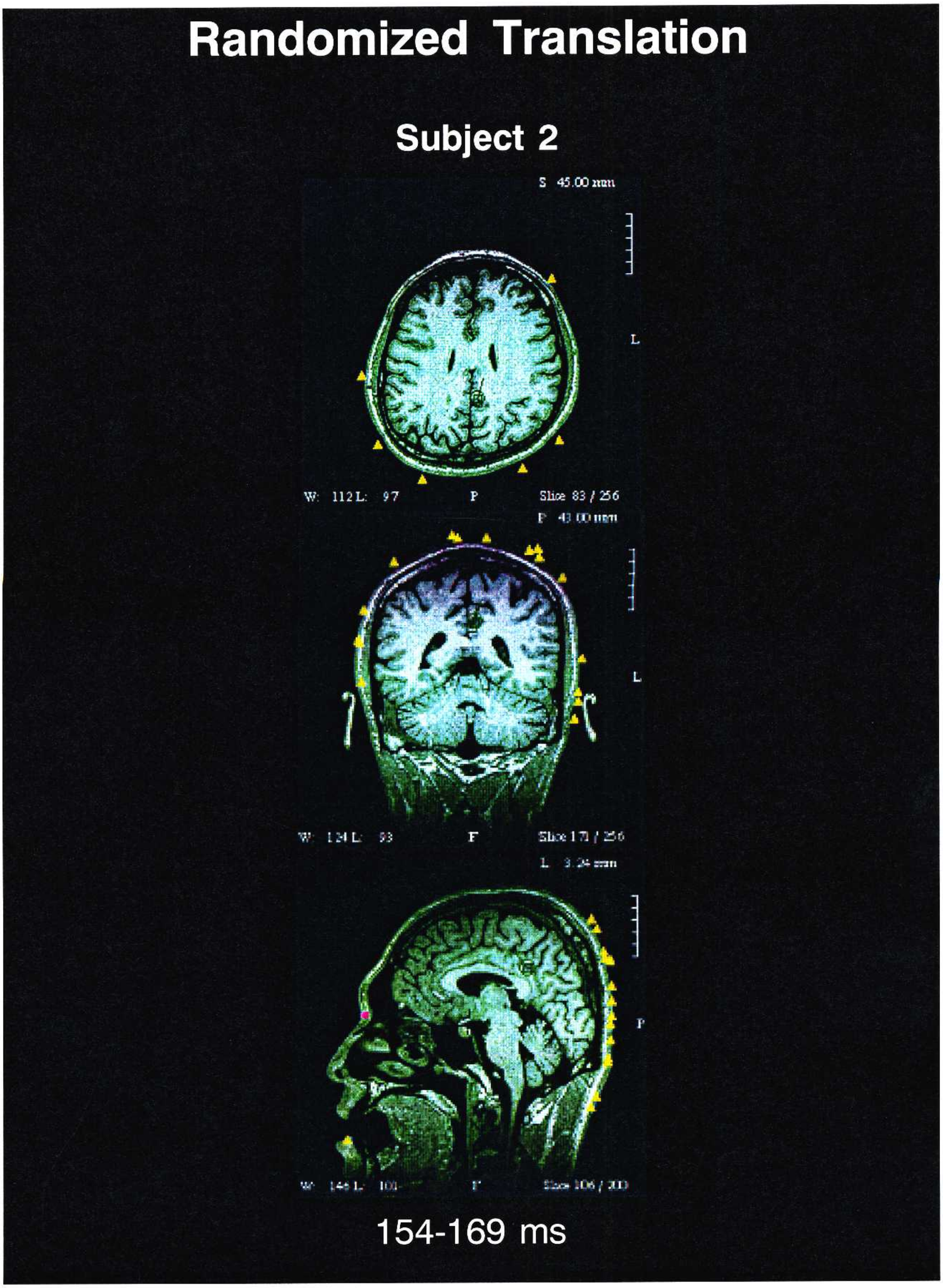


Fig. 4.26. Dipoles overlay on MR image of subject 2 in Randomized Translation.

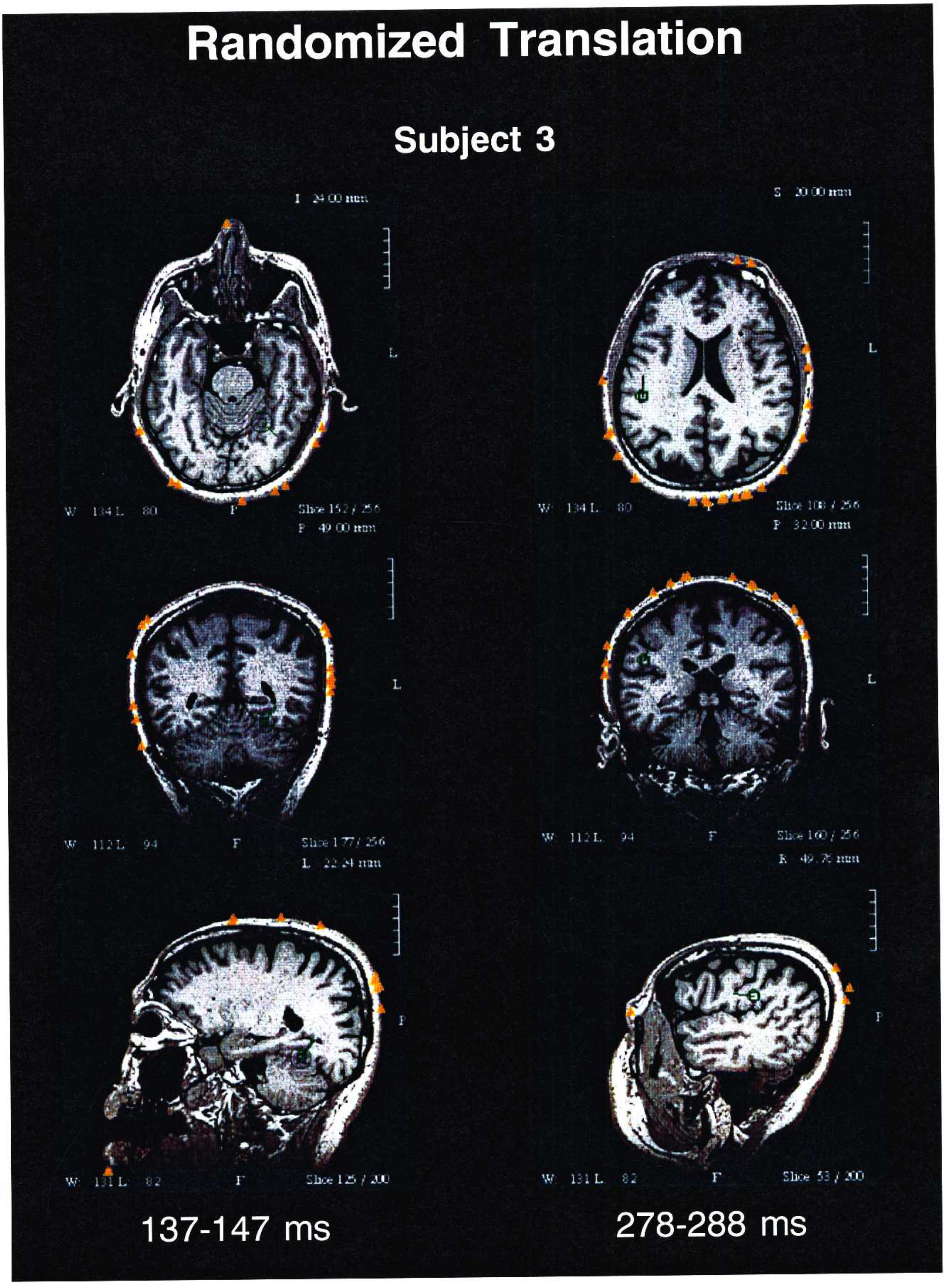


Fig. 4.27. Dipoles overlay on MR image of subject 3 in Randomized Translation.

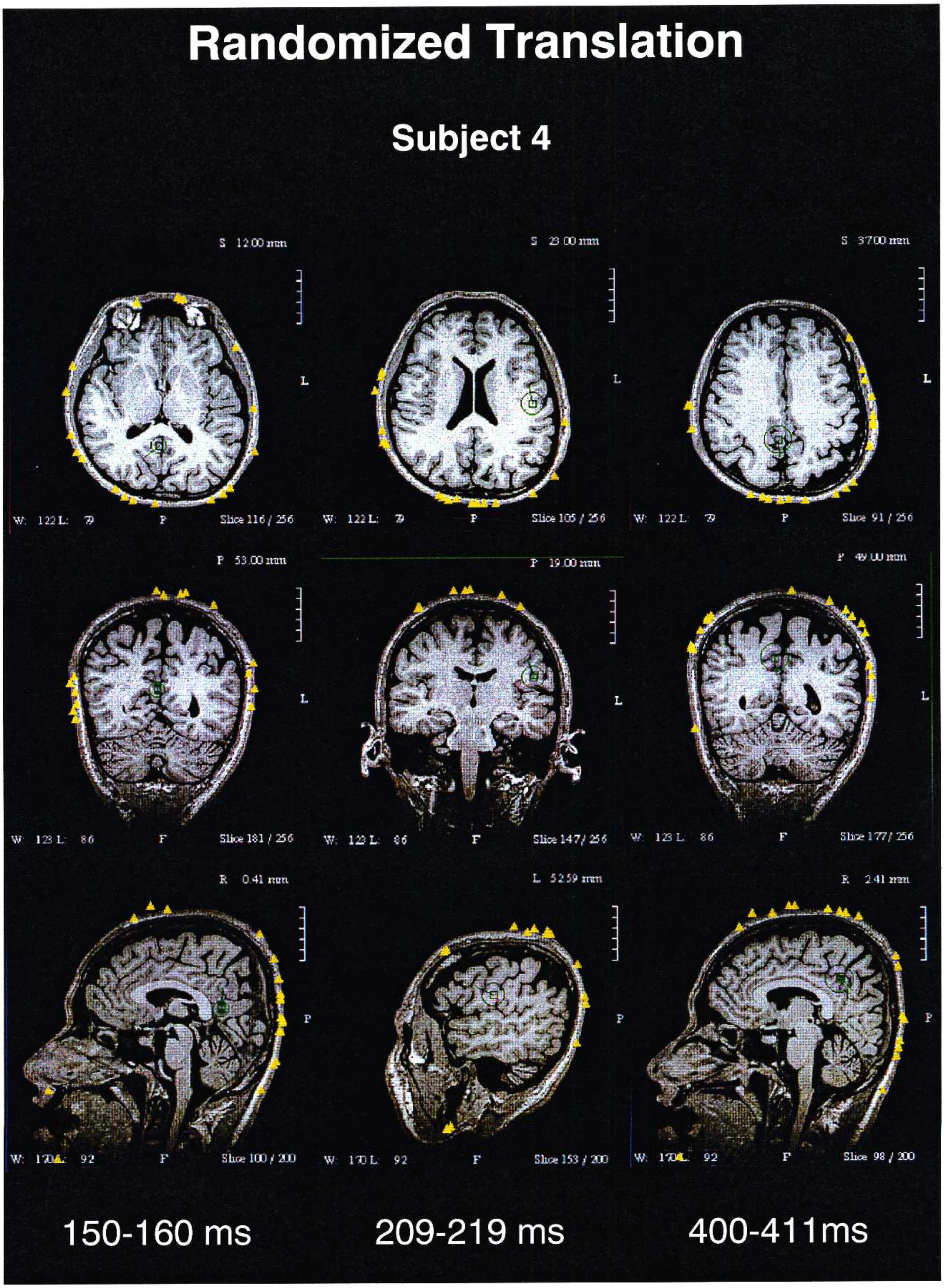


Fig. 4.28. Dipoles overlay on MR image of subject 4 in Randomized Translation.

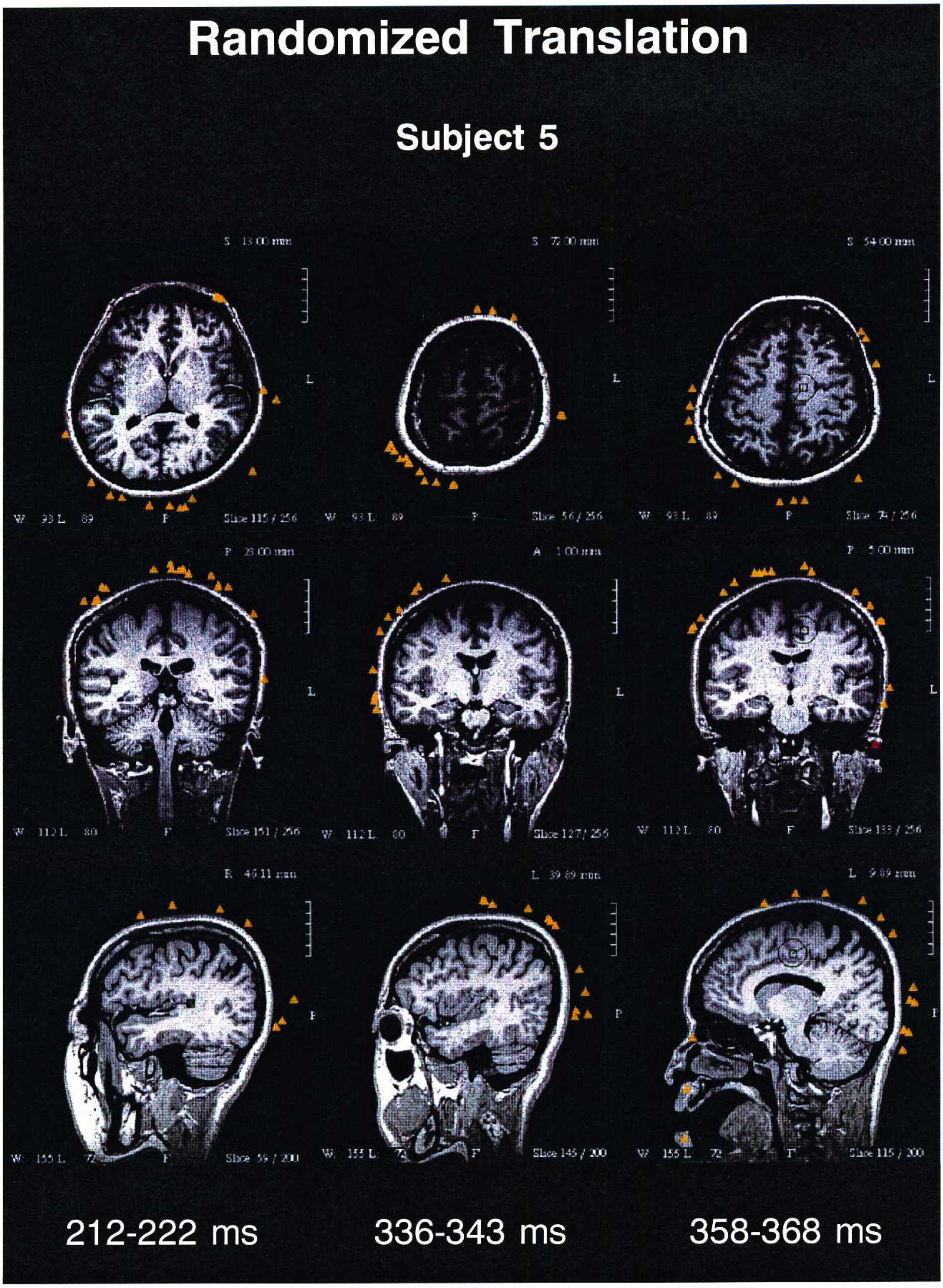


Fig. 4.29. Dipoles overlay on MR image of subject 5 in Randomized Translation.

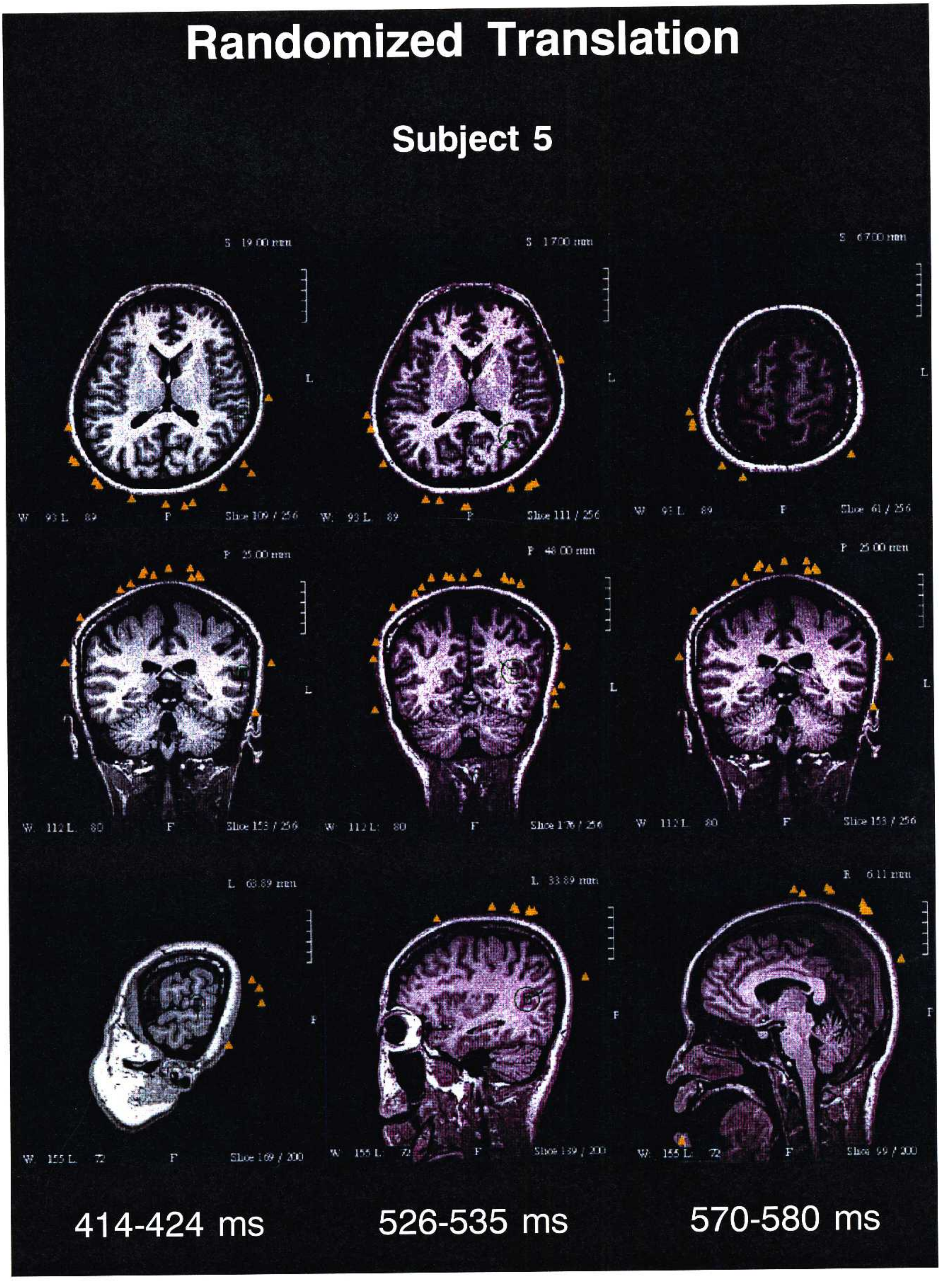


Fig. 4.30. Dipoles overlay on MR image of subject 5 in Randomized Translation.

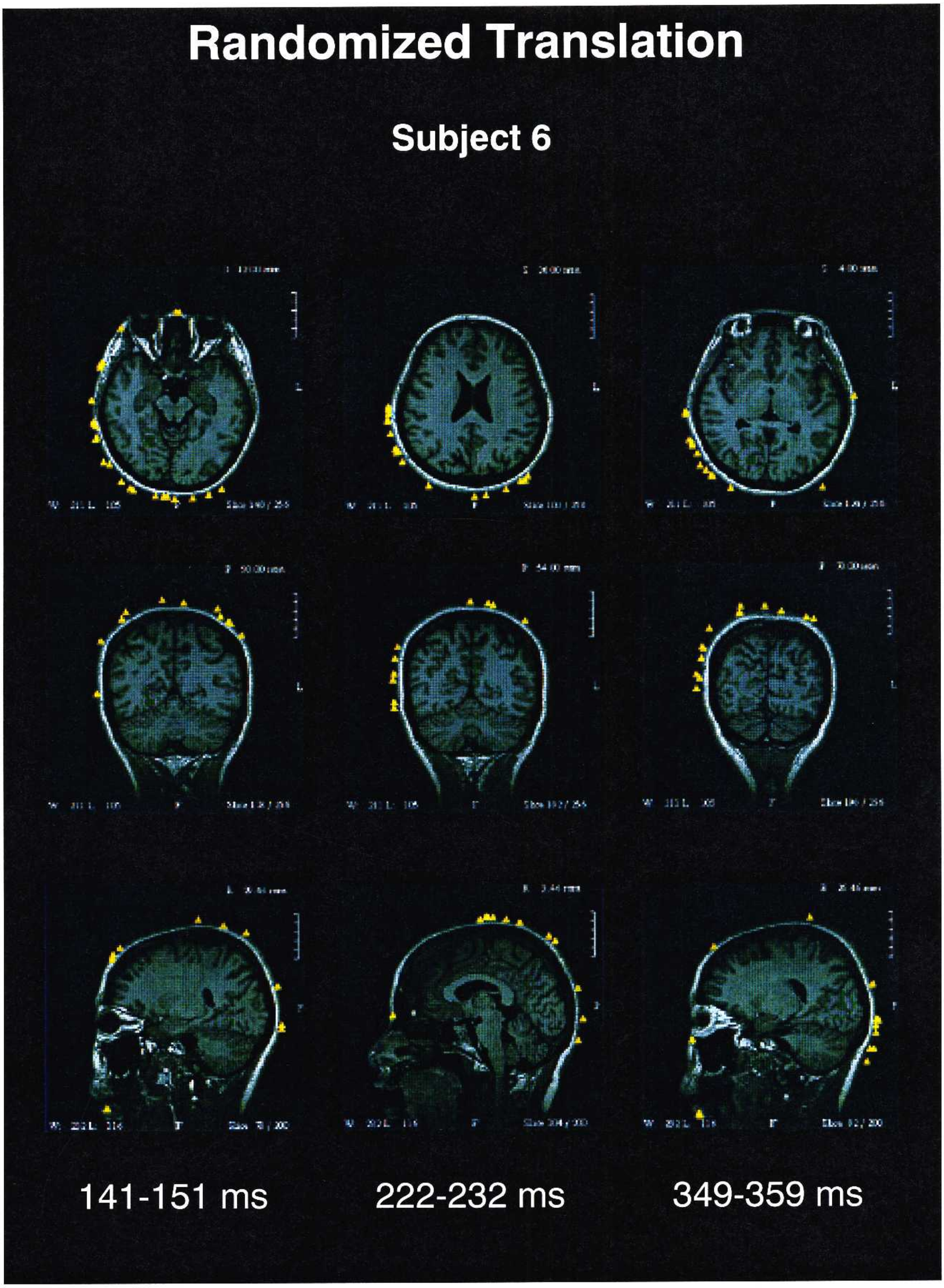


Fig. 4.31. Dipoles overlay on MR image of subject 6 in Randomized Translation.

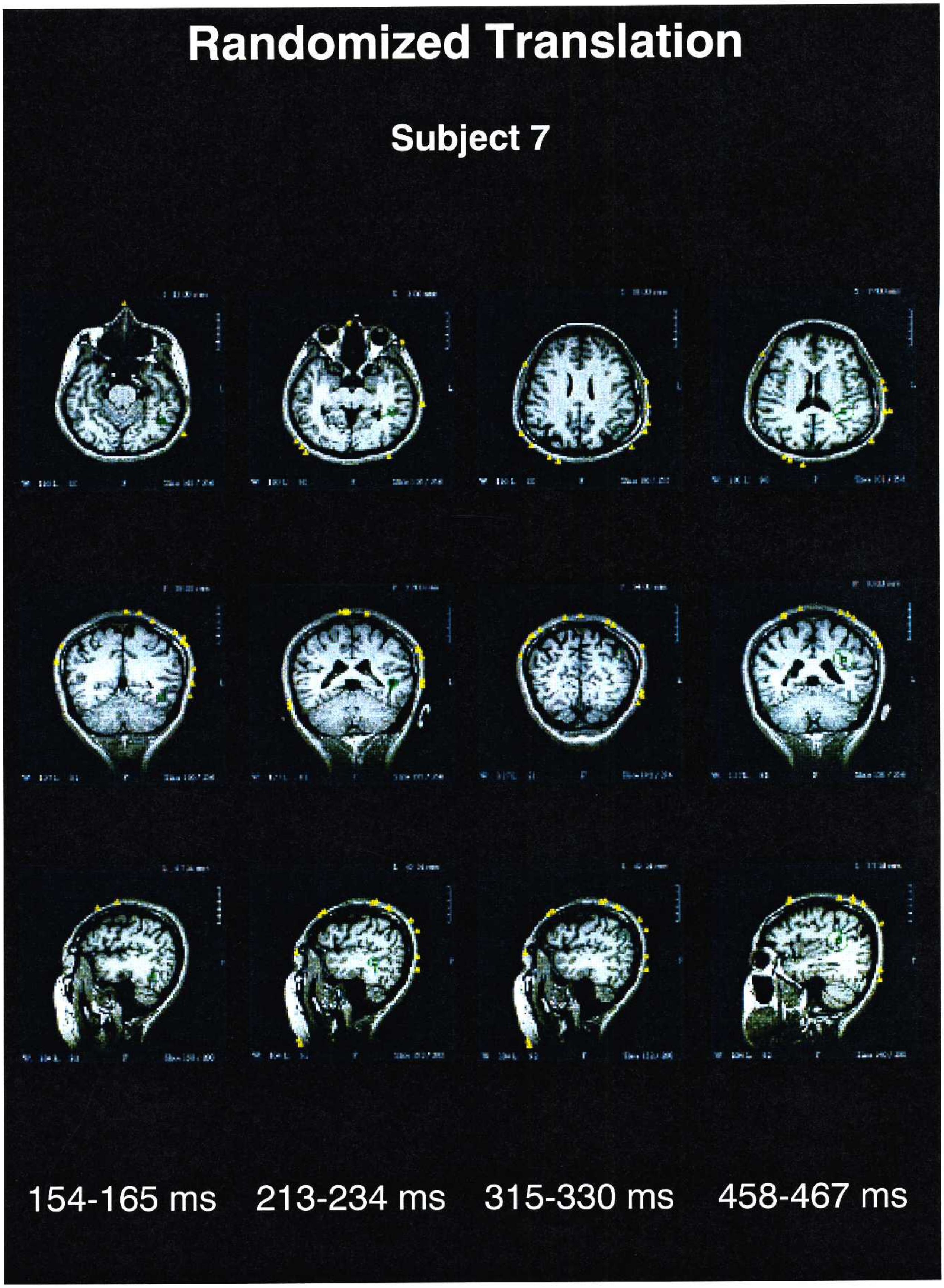


Fig. 4.32. Dipoles overlay on MR image of subject 7 in Randomized Translation.

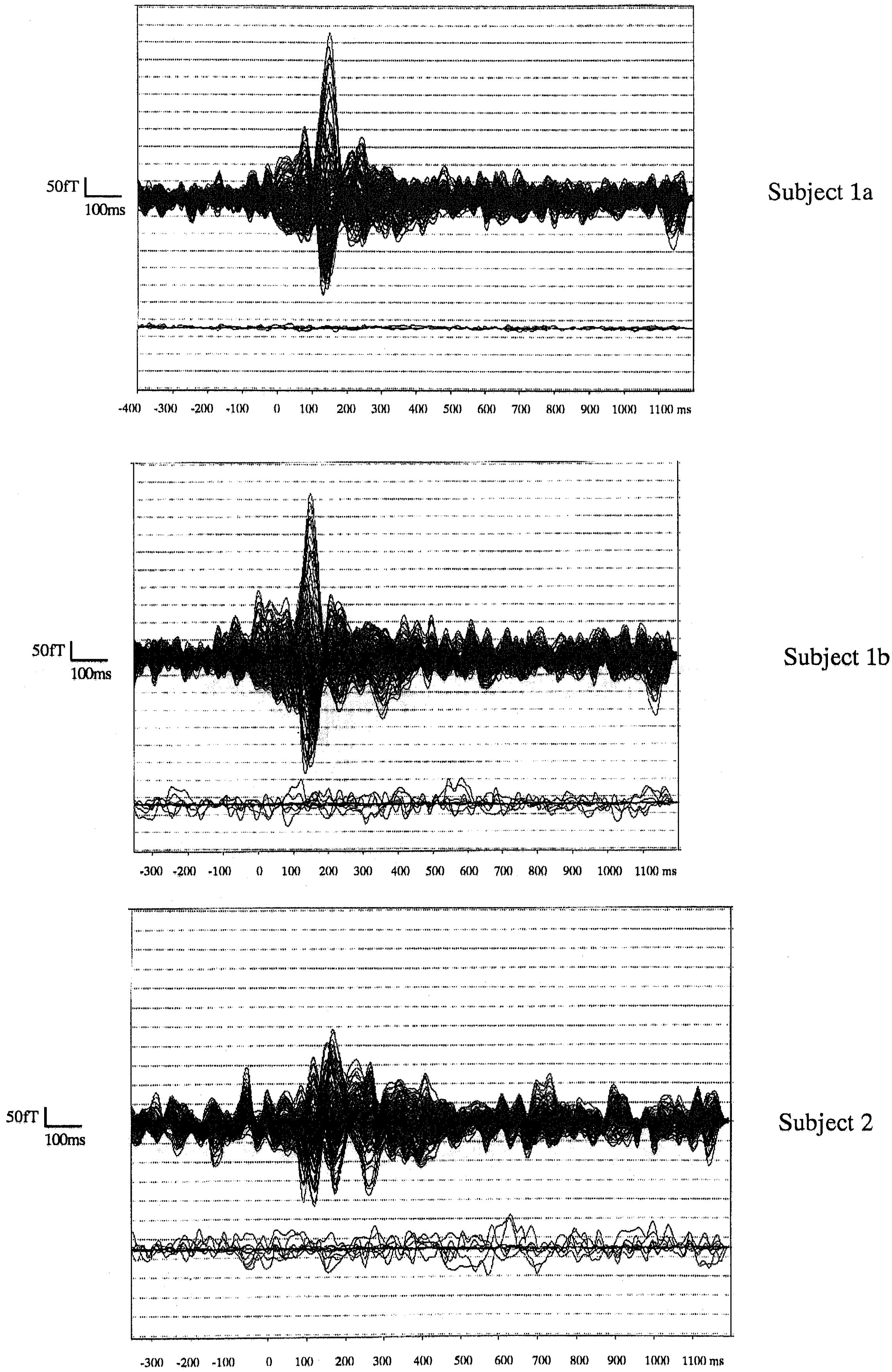
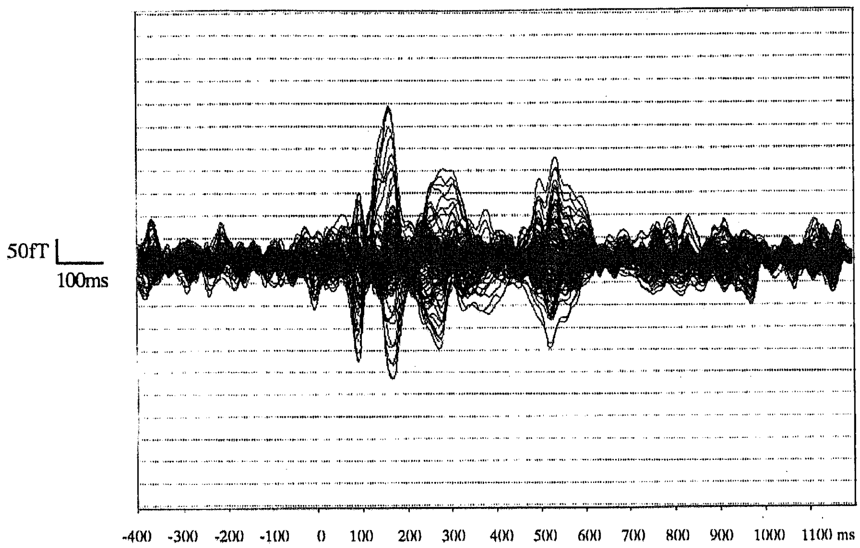
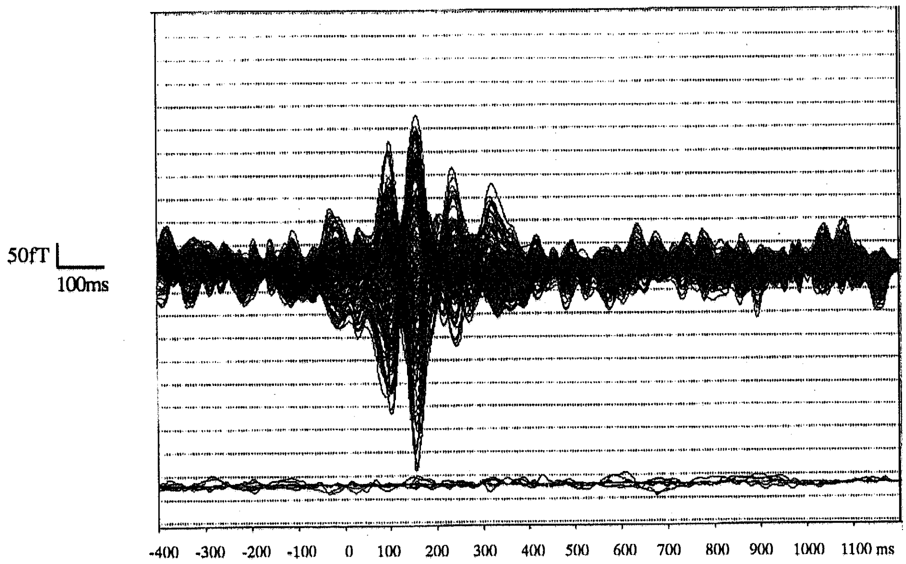


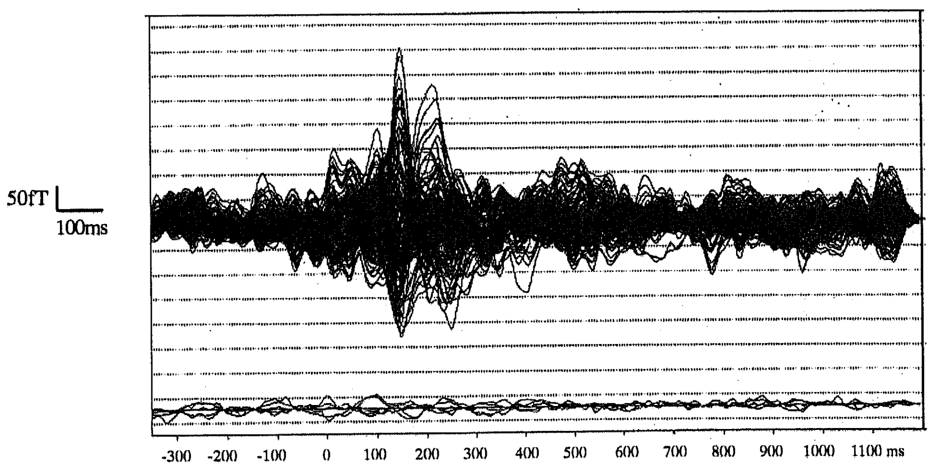
Fig. 4.33. MEG signal of subject 1a, 1b and 2 in Categorized Translation.



Subject 3

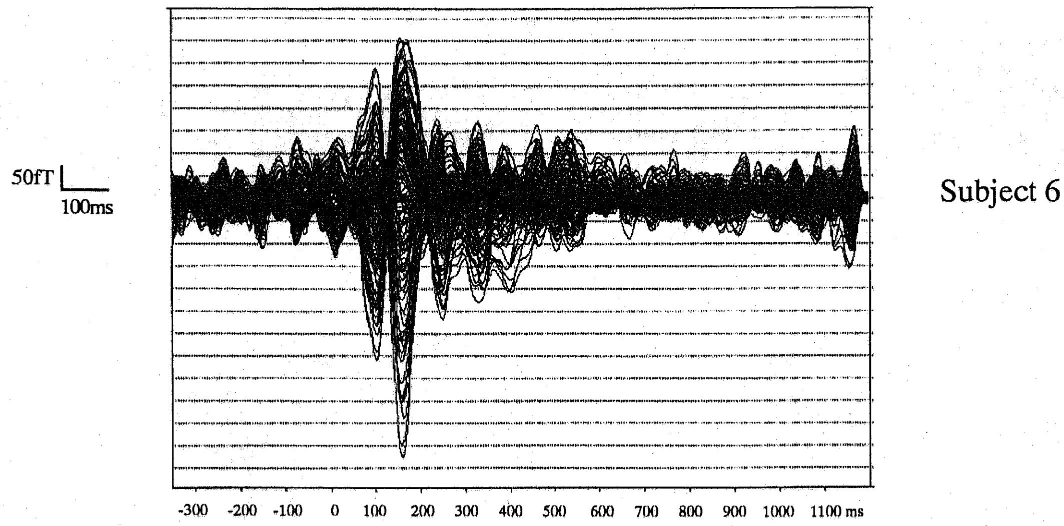


Subject 4



Subject 5

Fig. 4.34. MEG signal of subject 3, 4 and 5 in Categorized Translation.



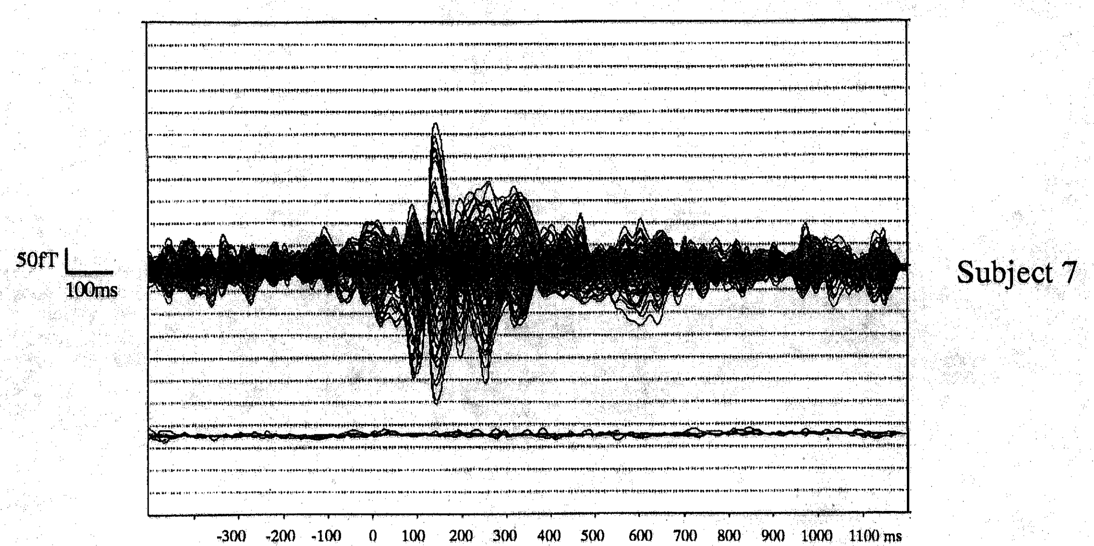


Fig. 4.35. MEG signal of subject 6 and 7 in Categorized Translation.

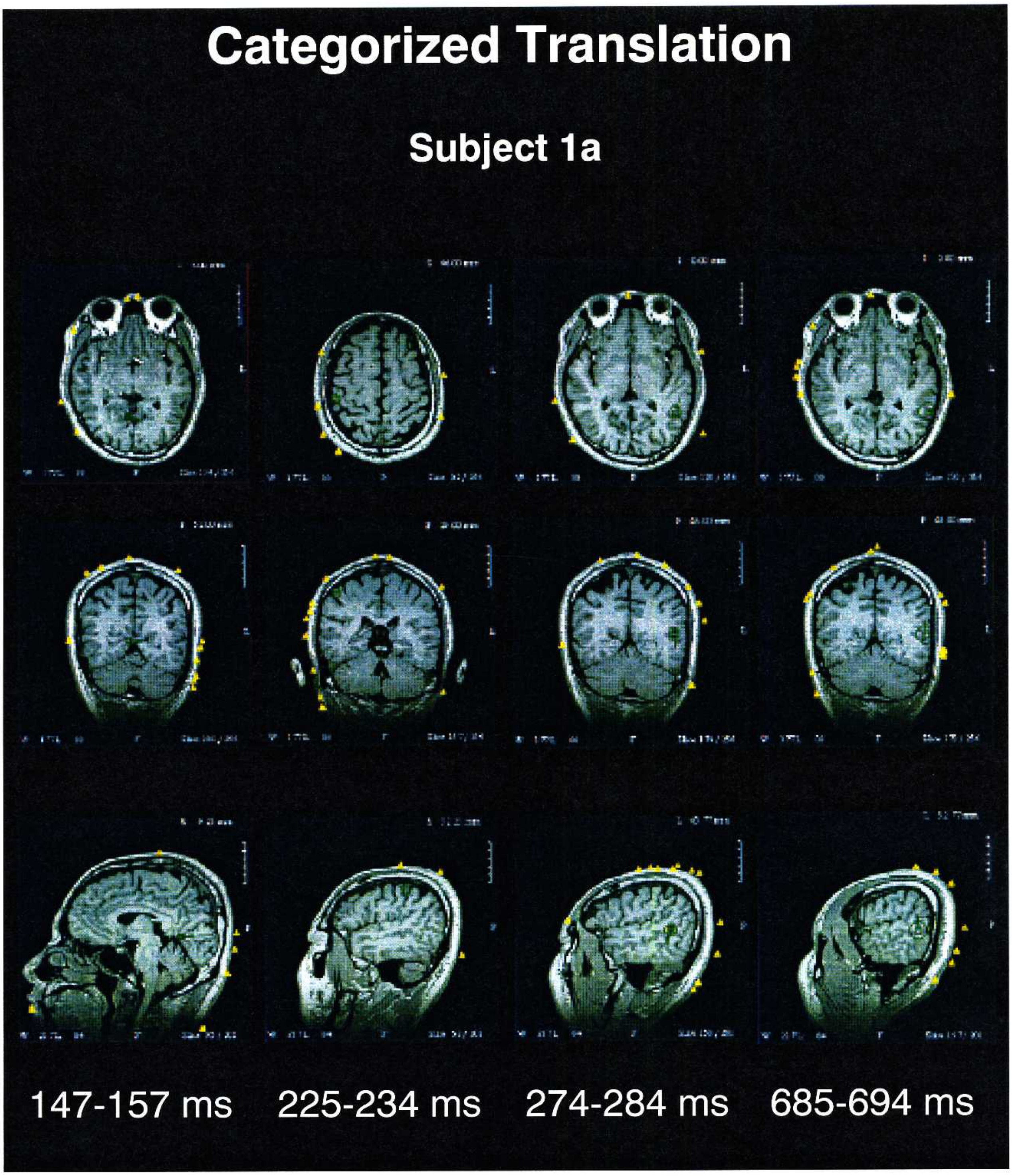


Fig. 4.36. Dipoles overlay on MR image of subject 1a in Categorized Translation.

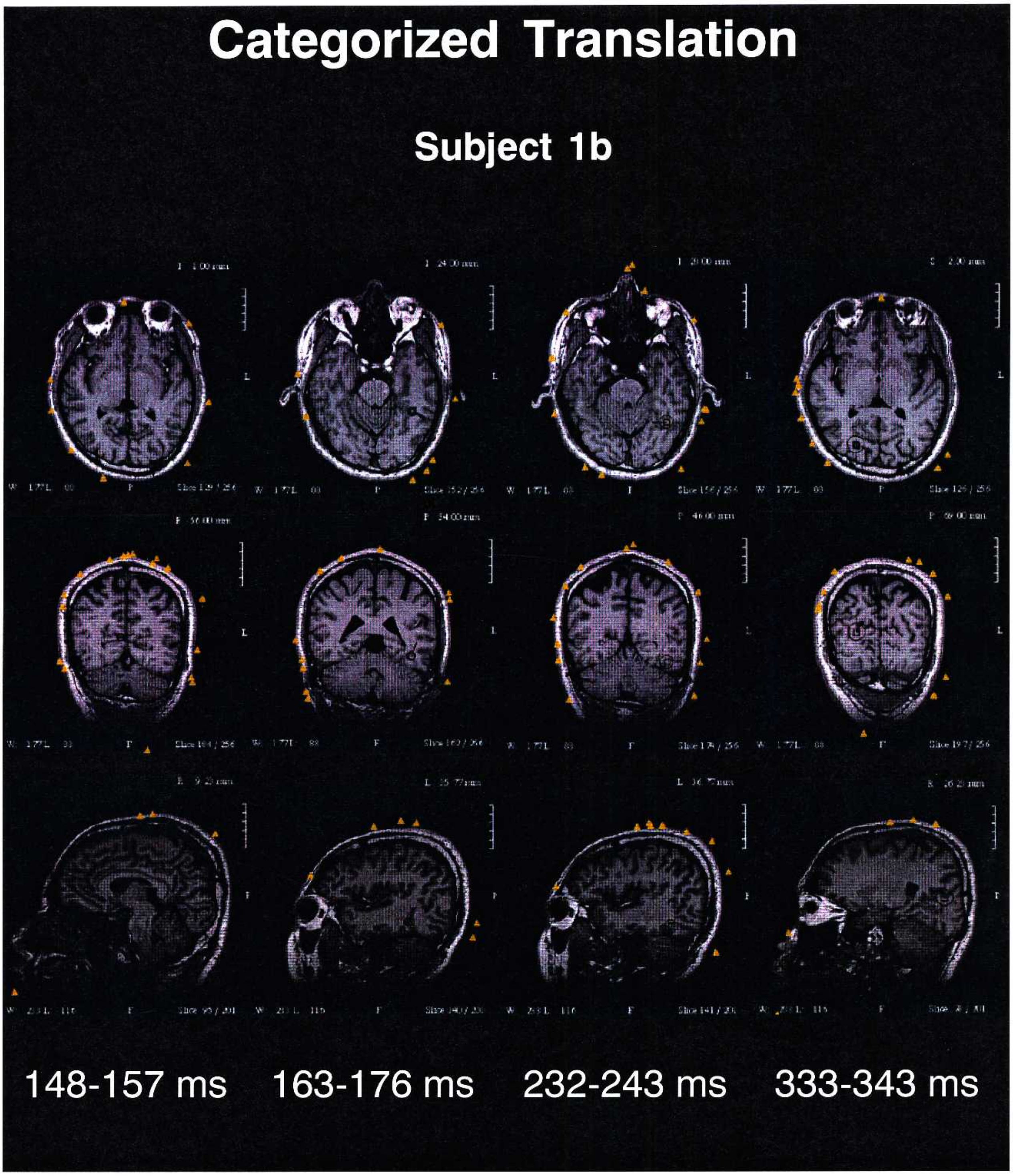


Fig. 4.37. Dipoles overlay on MR image of subject 1b in Categorized Translation.

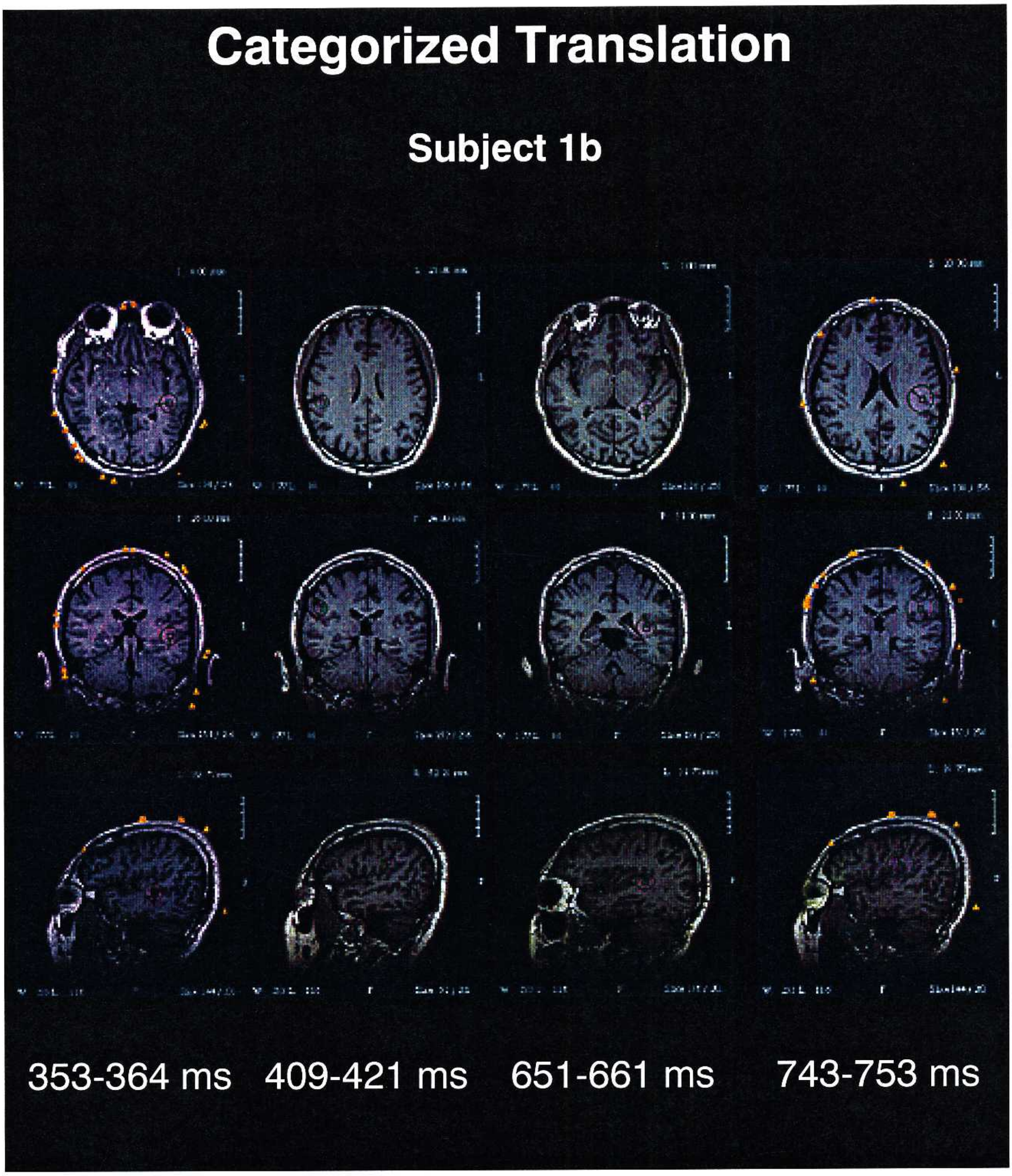


Fig. 4.38. Dipoles overlay on MR image of subject 1b in Categorized Translation.

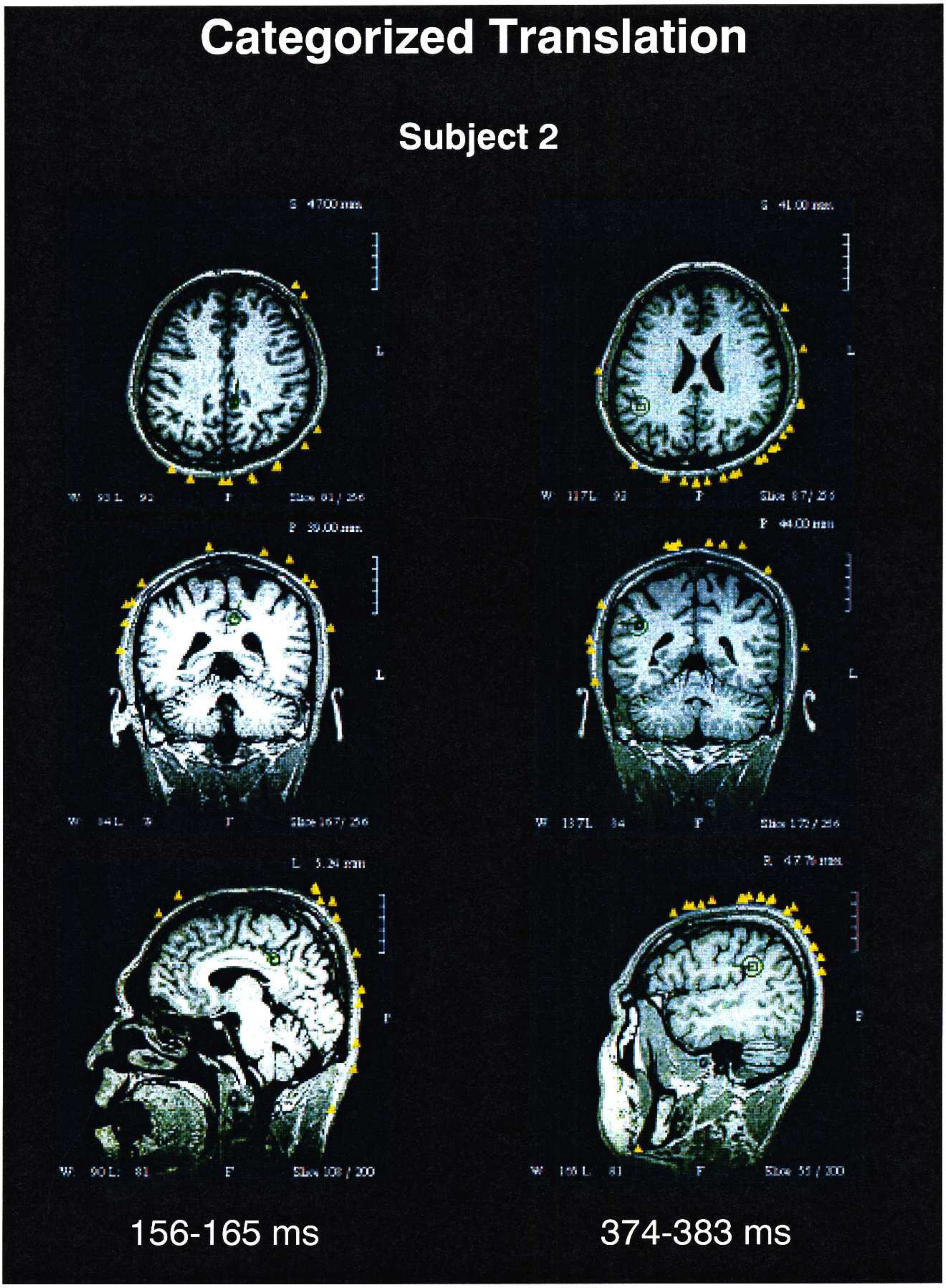


Fig. 4.39. Dipoles overlay on MR image of subject 2 in Categorized Translation.

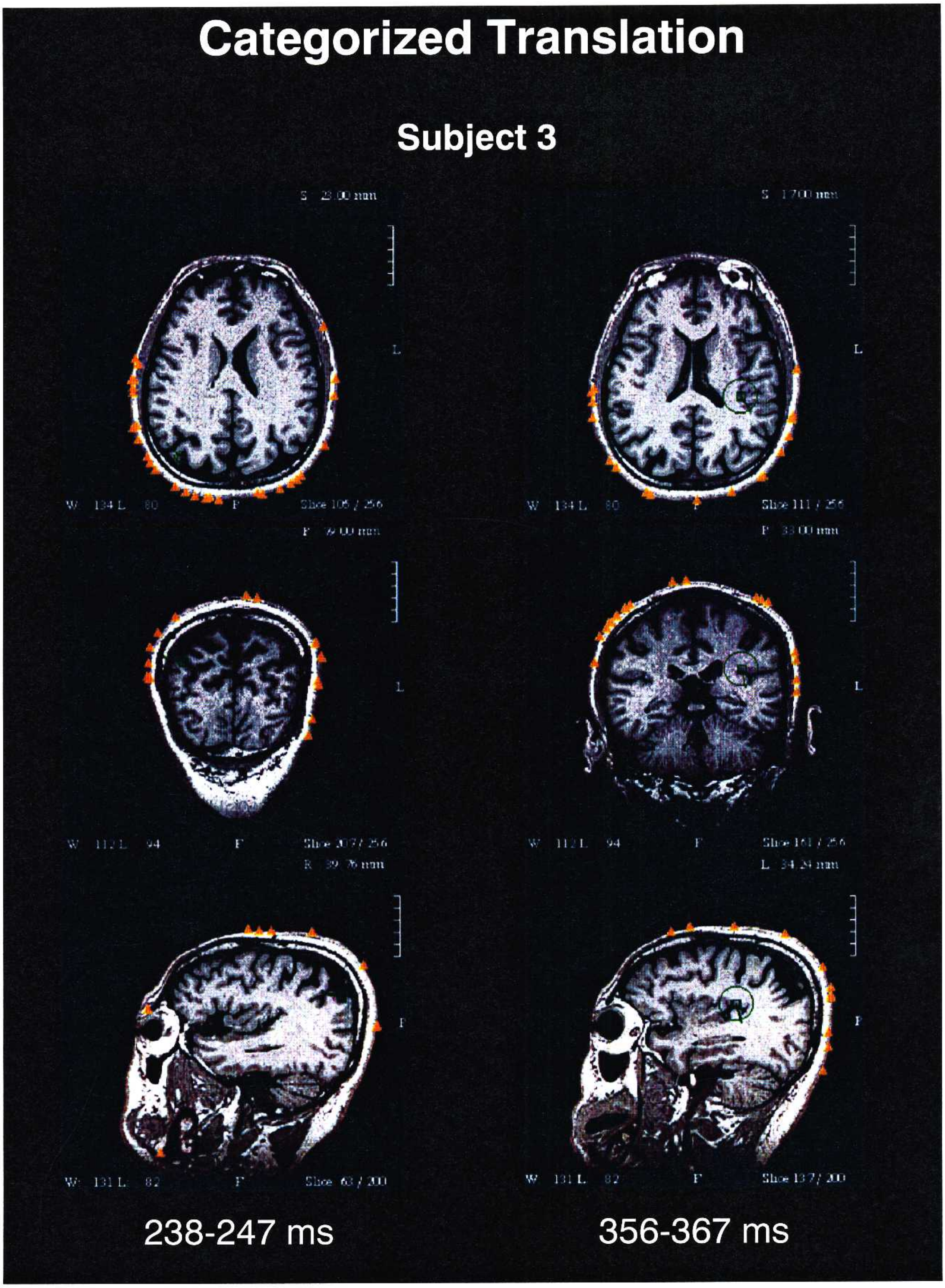


Fig. 4.40. Dipoles overlay on MR image of subject 3 in Categorized Translation.

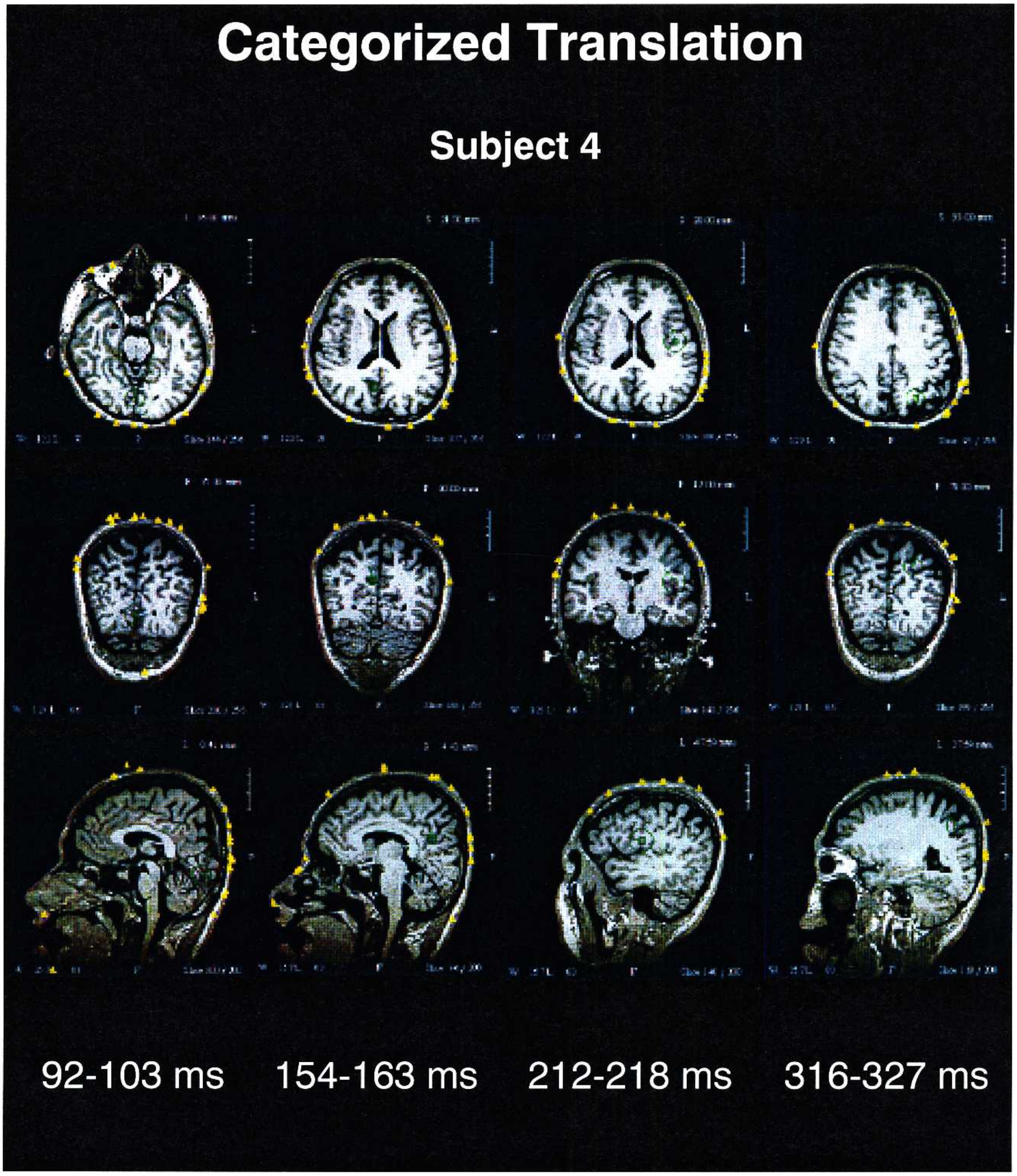


Fig. 4.41. Dipoles overlay on MR image of subject 4 in Categorized Translation.

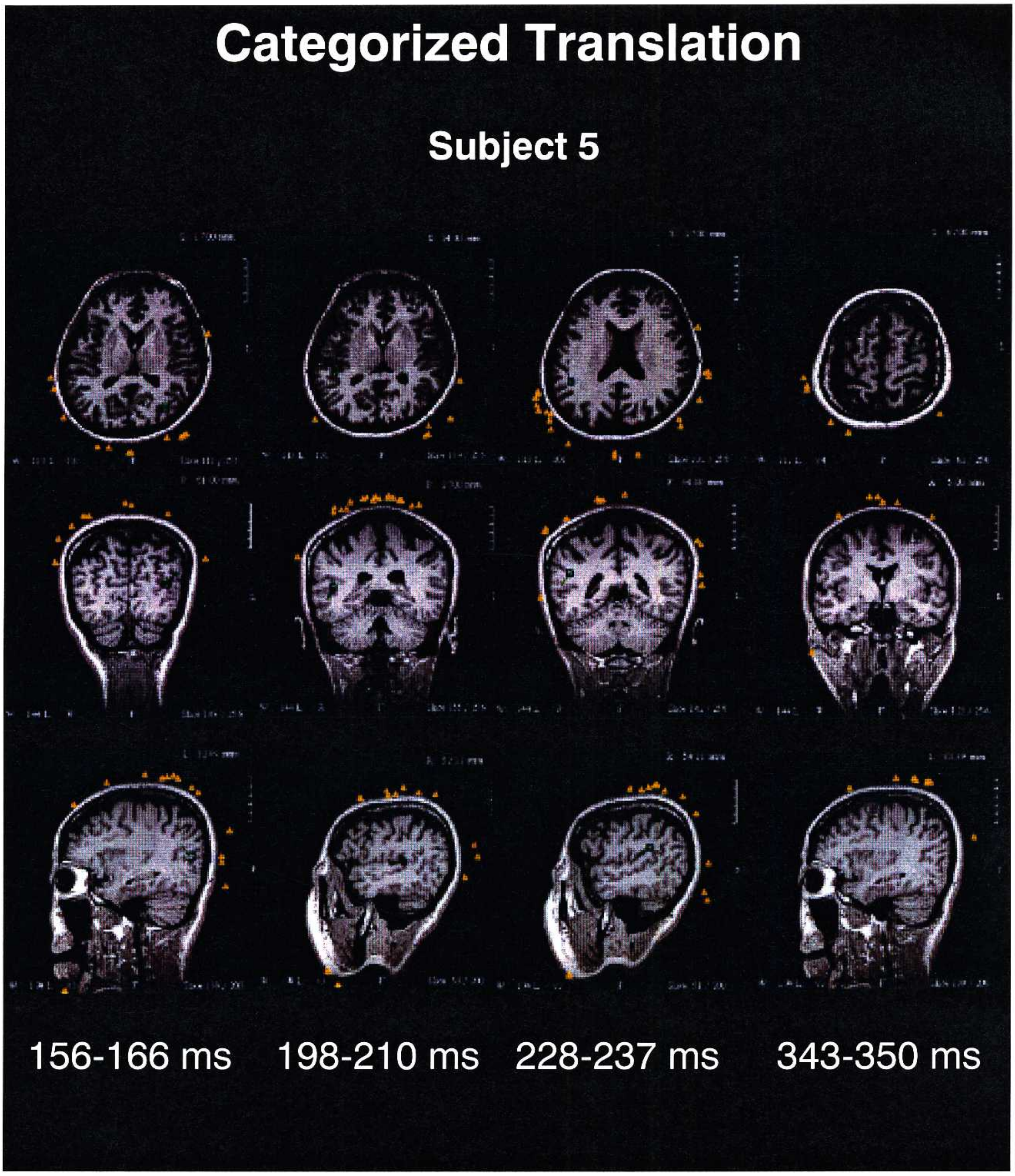


Fig. 4.42. Dipoles overlay on MR image of subject 5 in Categorized Translation.

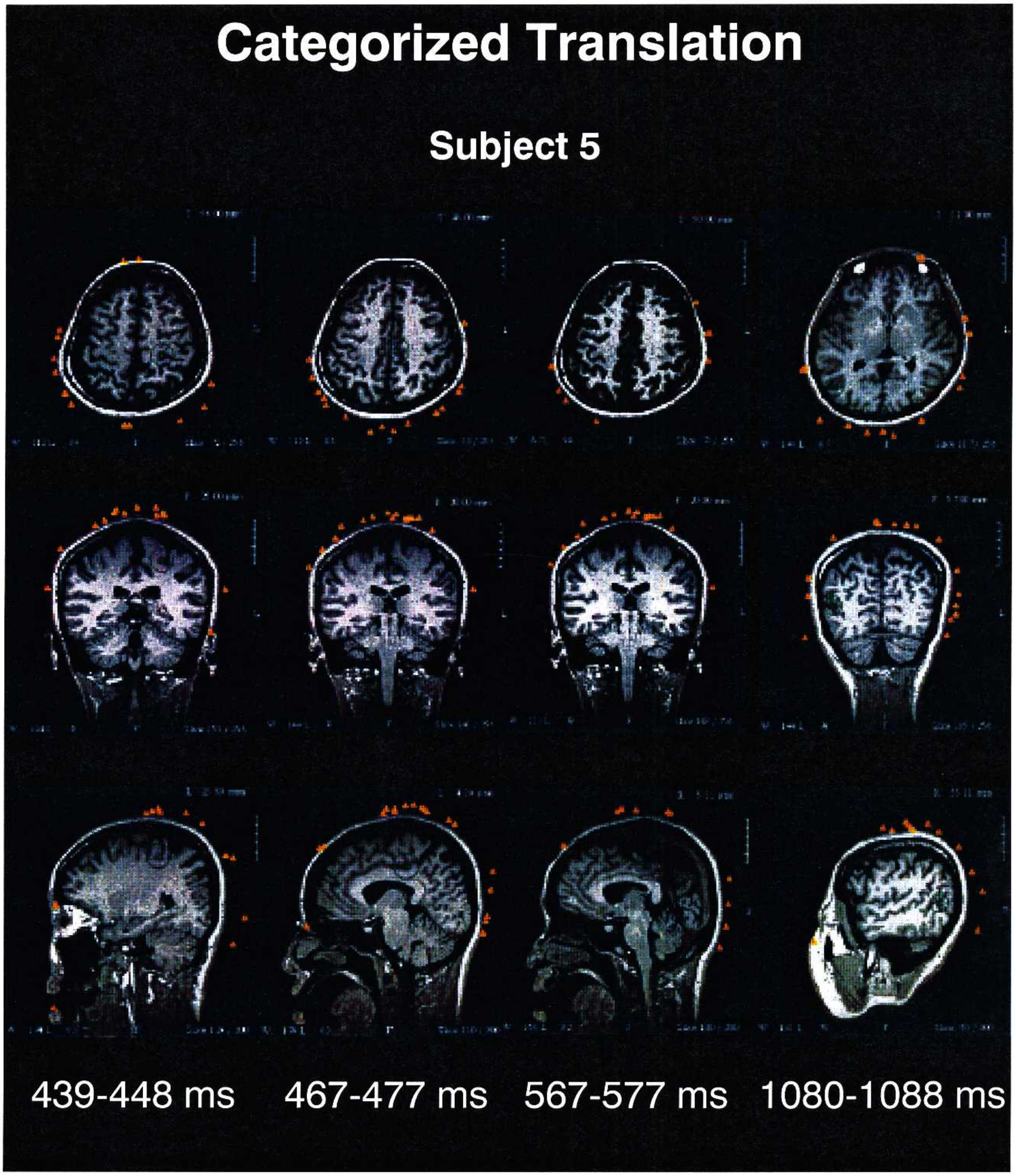


Fig. 4.43. Dipoles overlay on MR image of subject 5 in Categorized Translation.

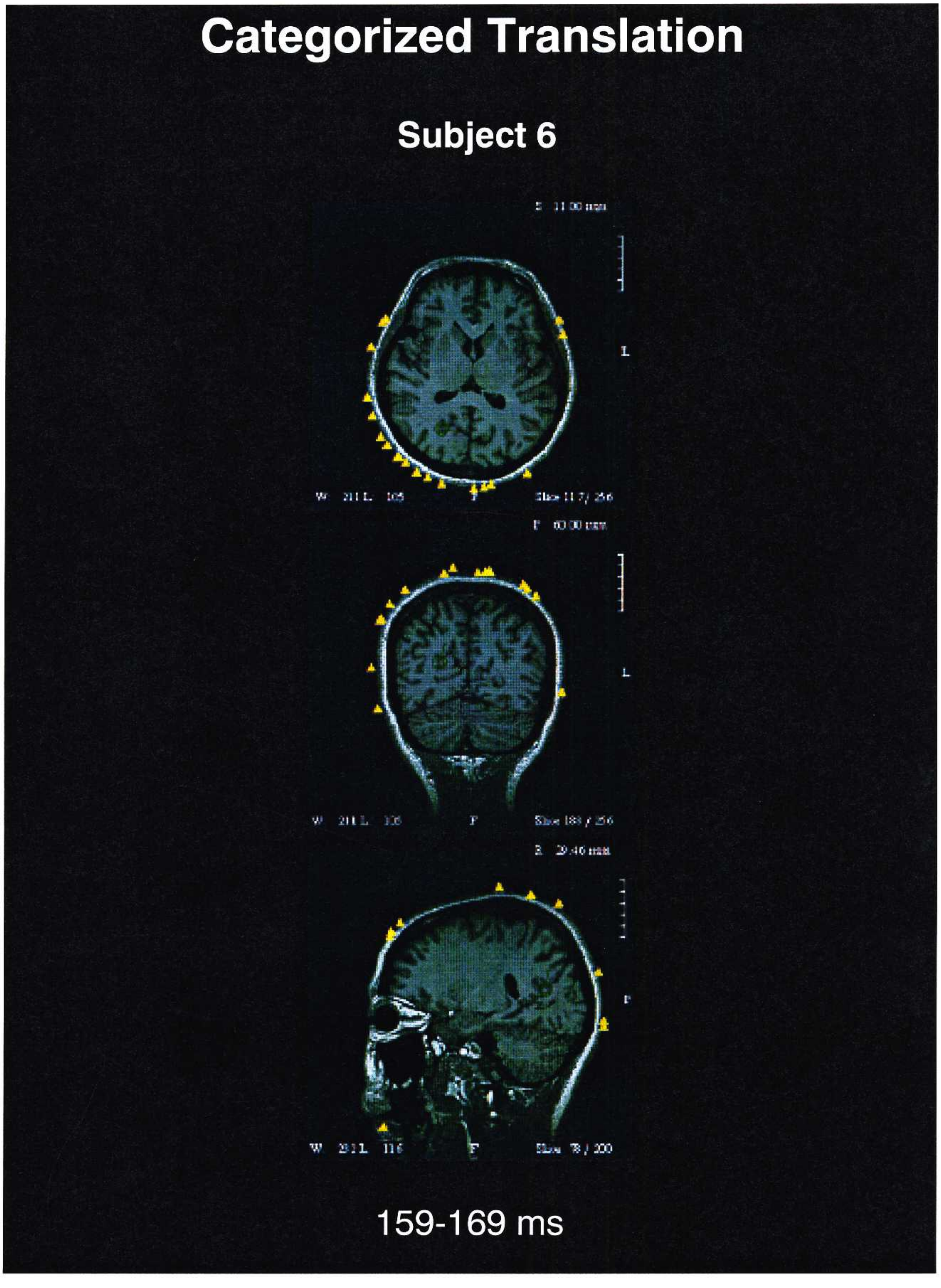


Fig. 4.44. Dipoles overlay on MR image of subject 6 in Categorized Translation.

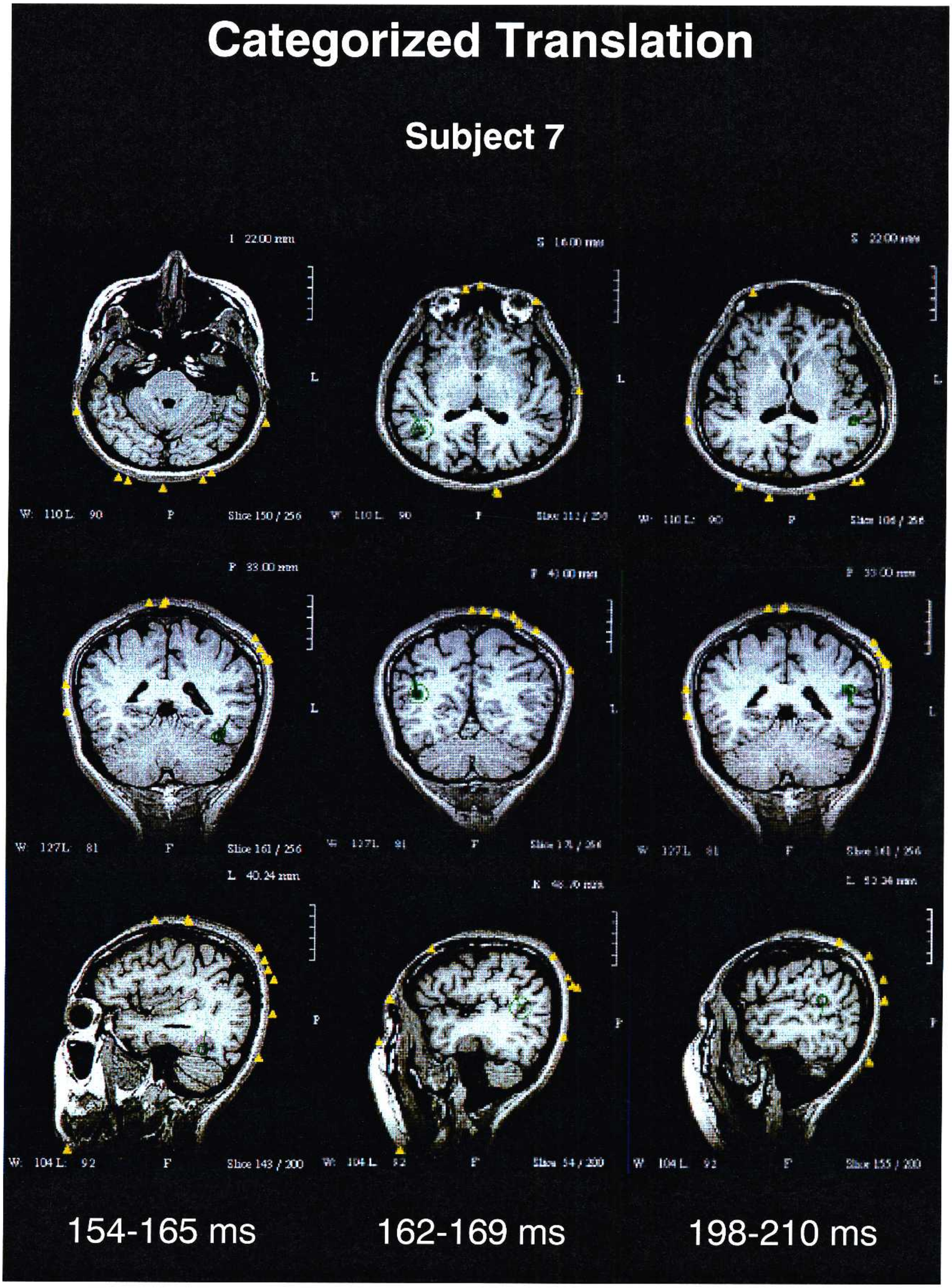


Fig. 4.45. Dipoles overlay on MR image of subject 7 in Categorized Translation.

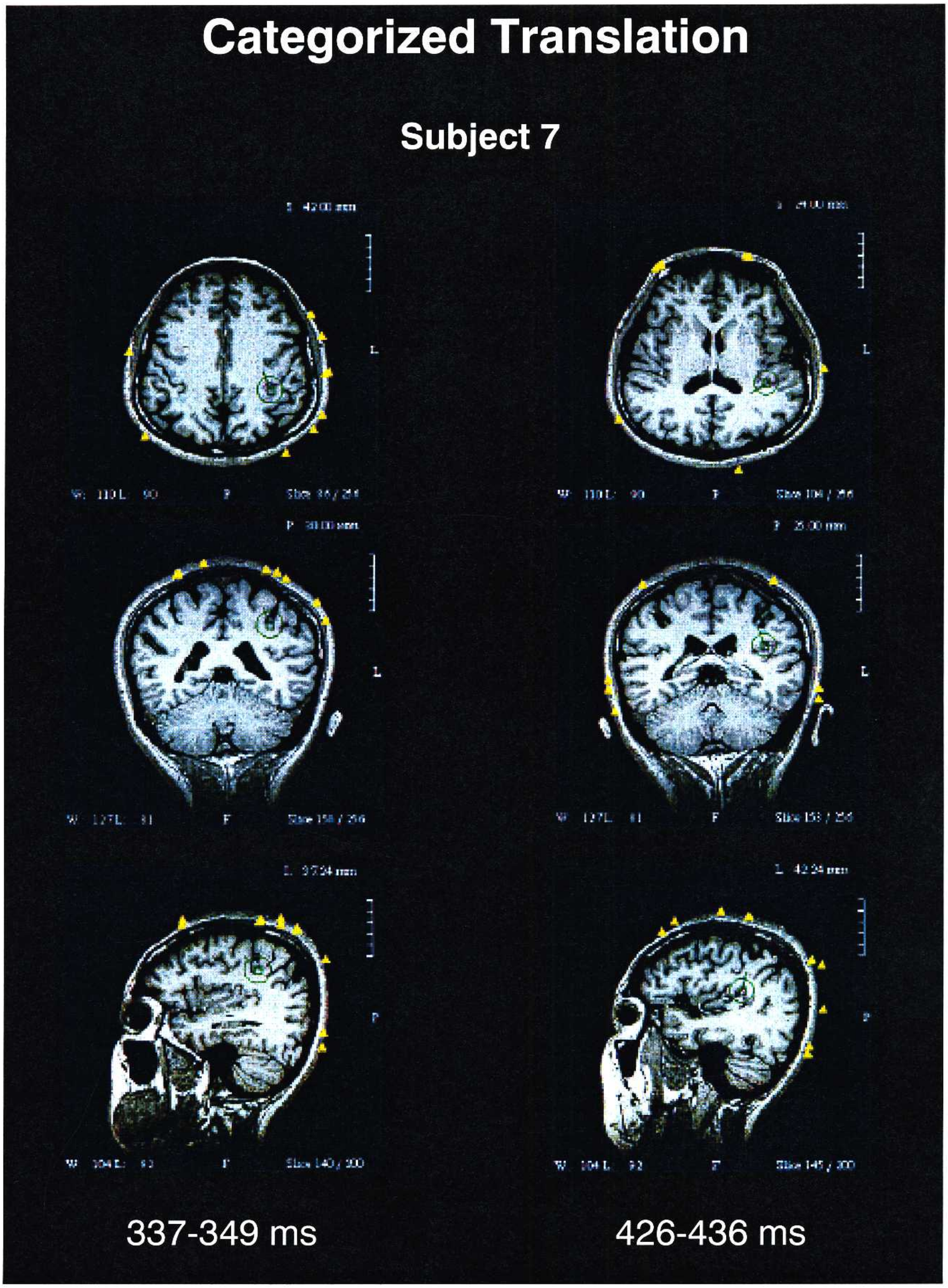


Fig. 4.46. Dipoles overlay on MR image of subject 7 in Categorized Translation.

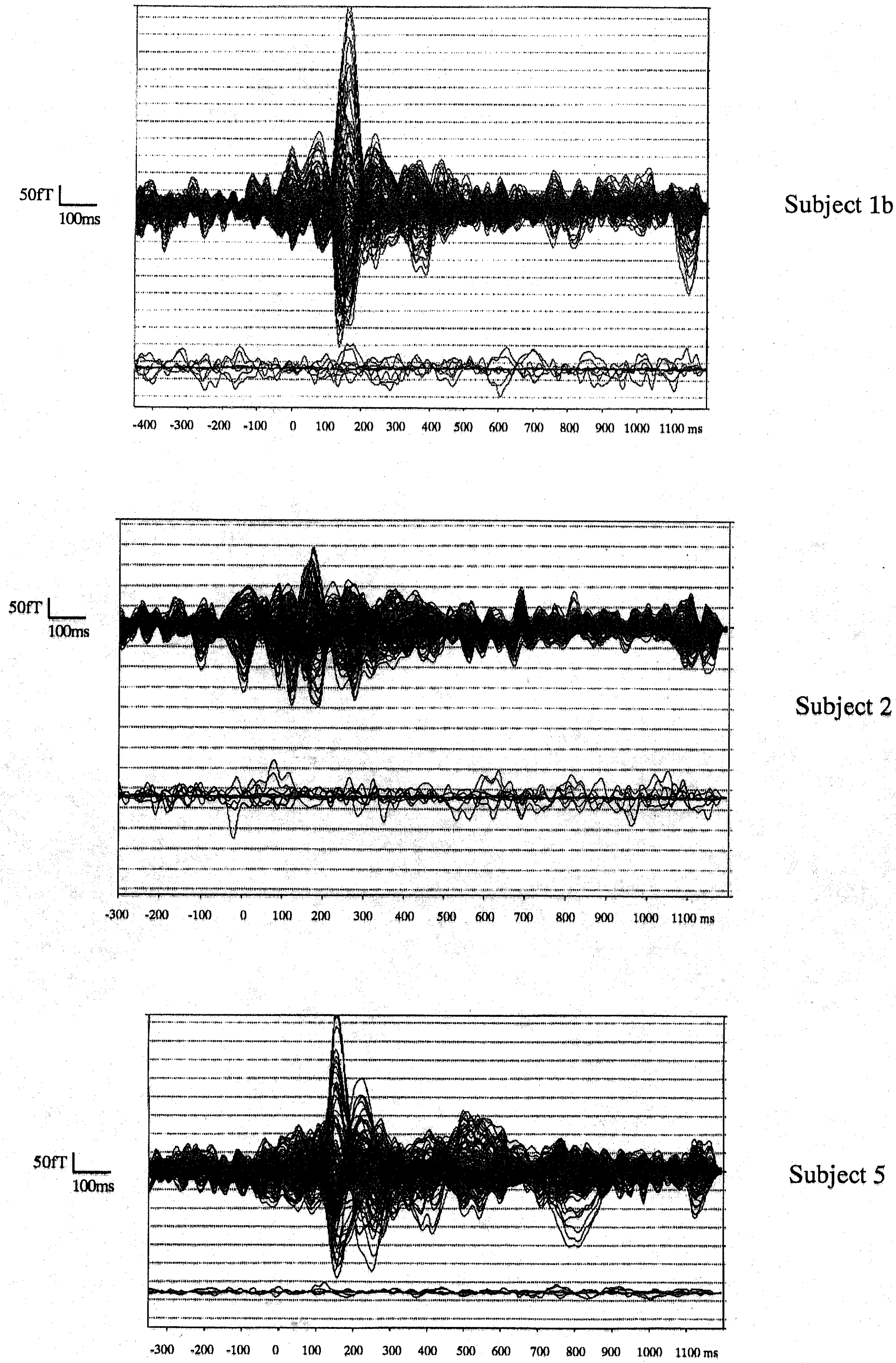


Fig. 4.47. MEG signal of subject 1b, 2 and 5 in Verb Generation.

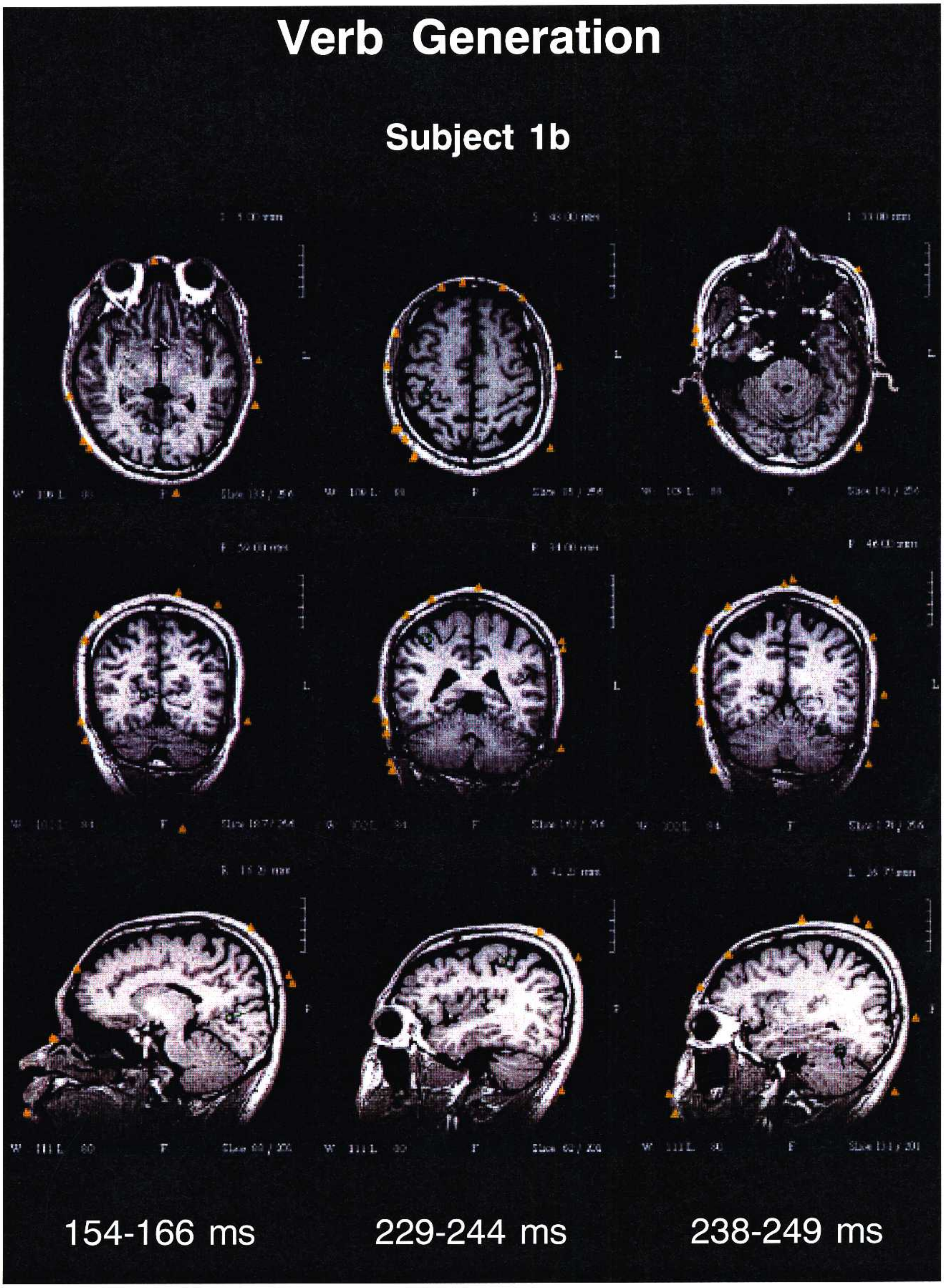


Fig. 4.48. Dipoles overlay on MR image of subject 1b in Verb Generation.

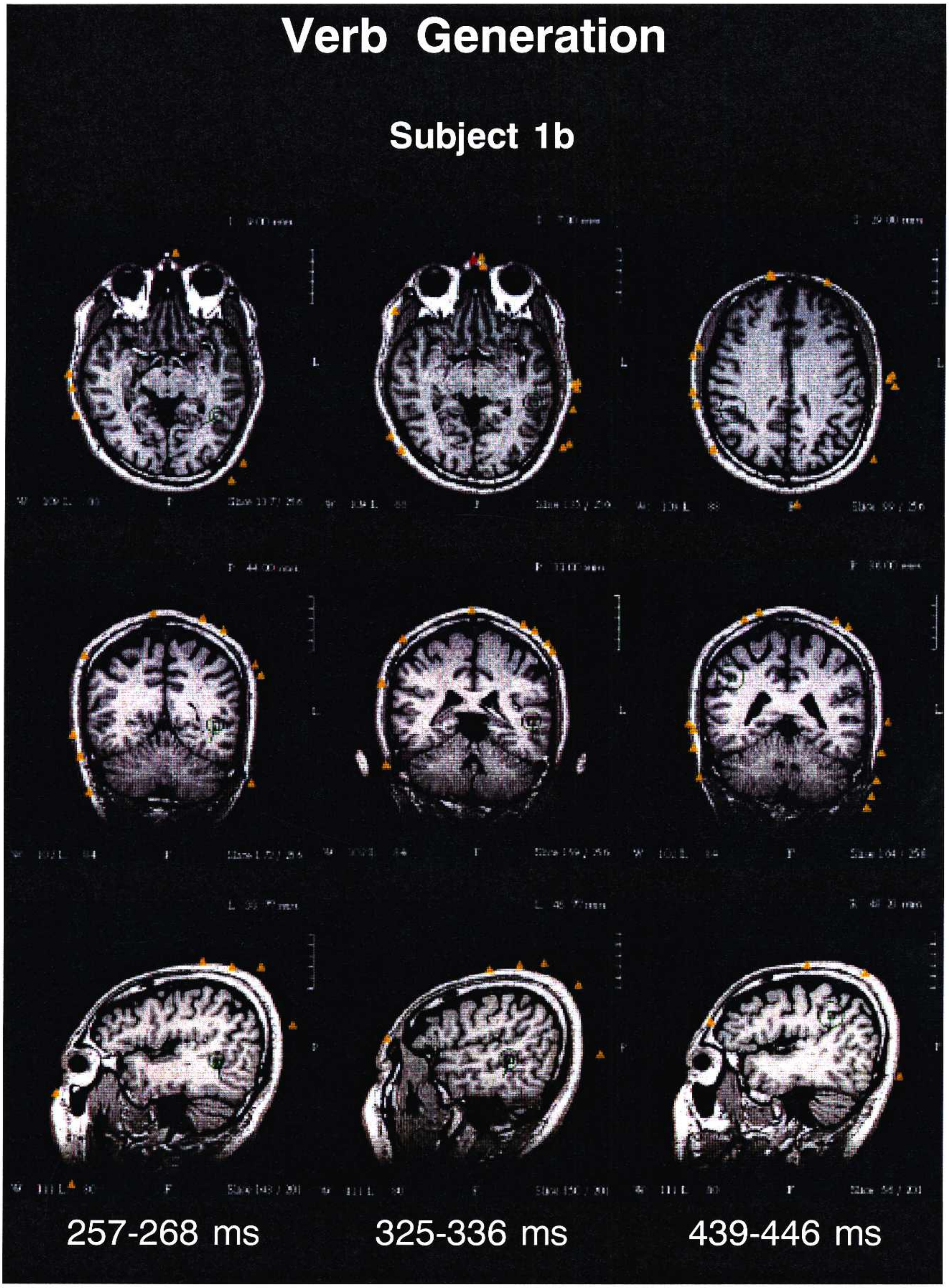


Fig. 4.49. Dipoles overlay on MR image of subject 1b in Verb Generation.

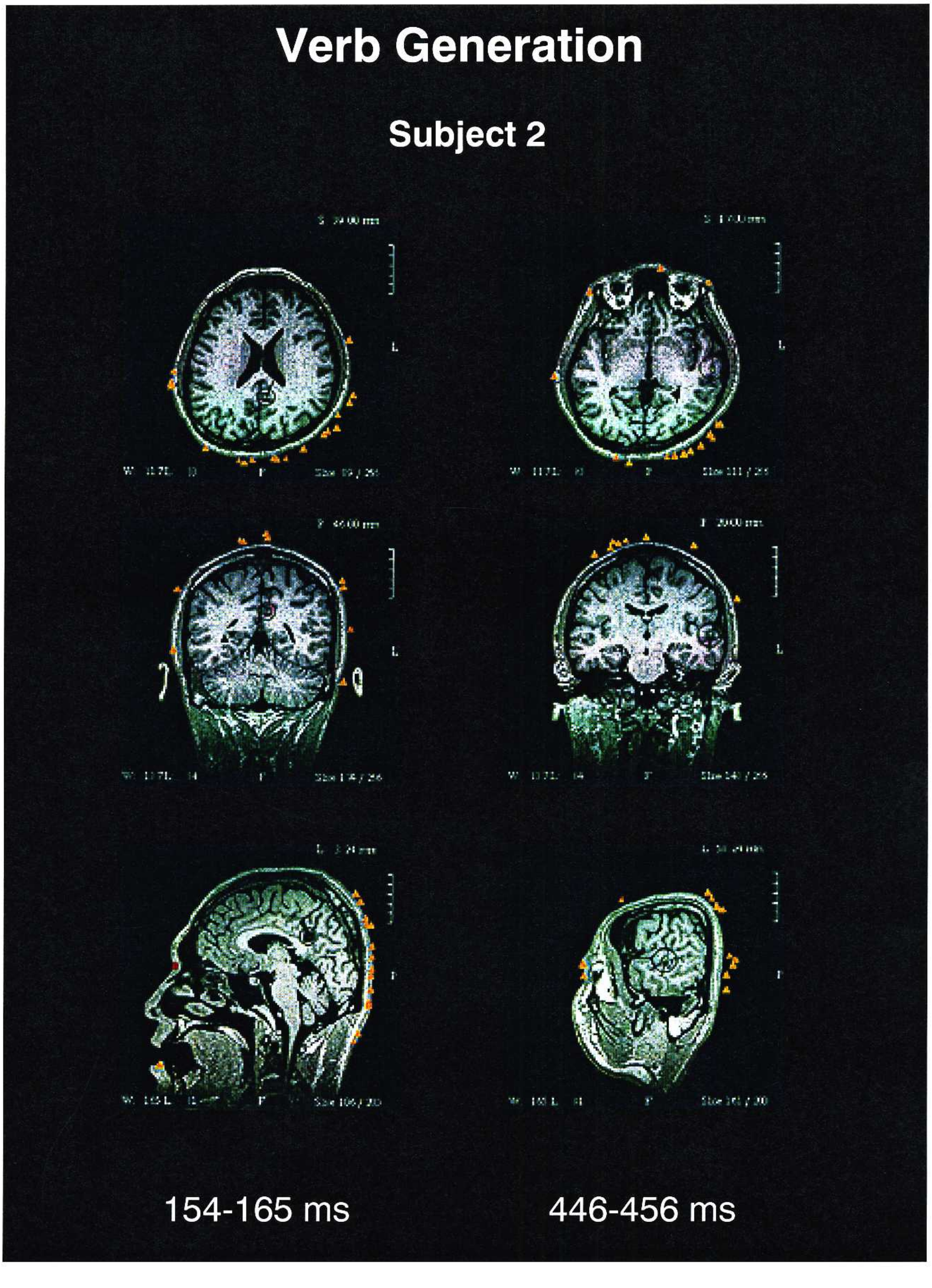


Fig. 4.50. Dipoles overlay on MR image of subject 2 in Verb Generation.

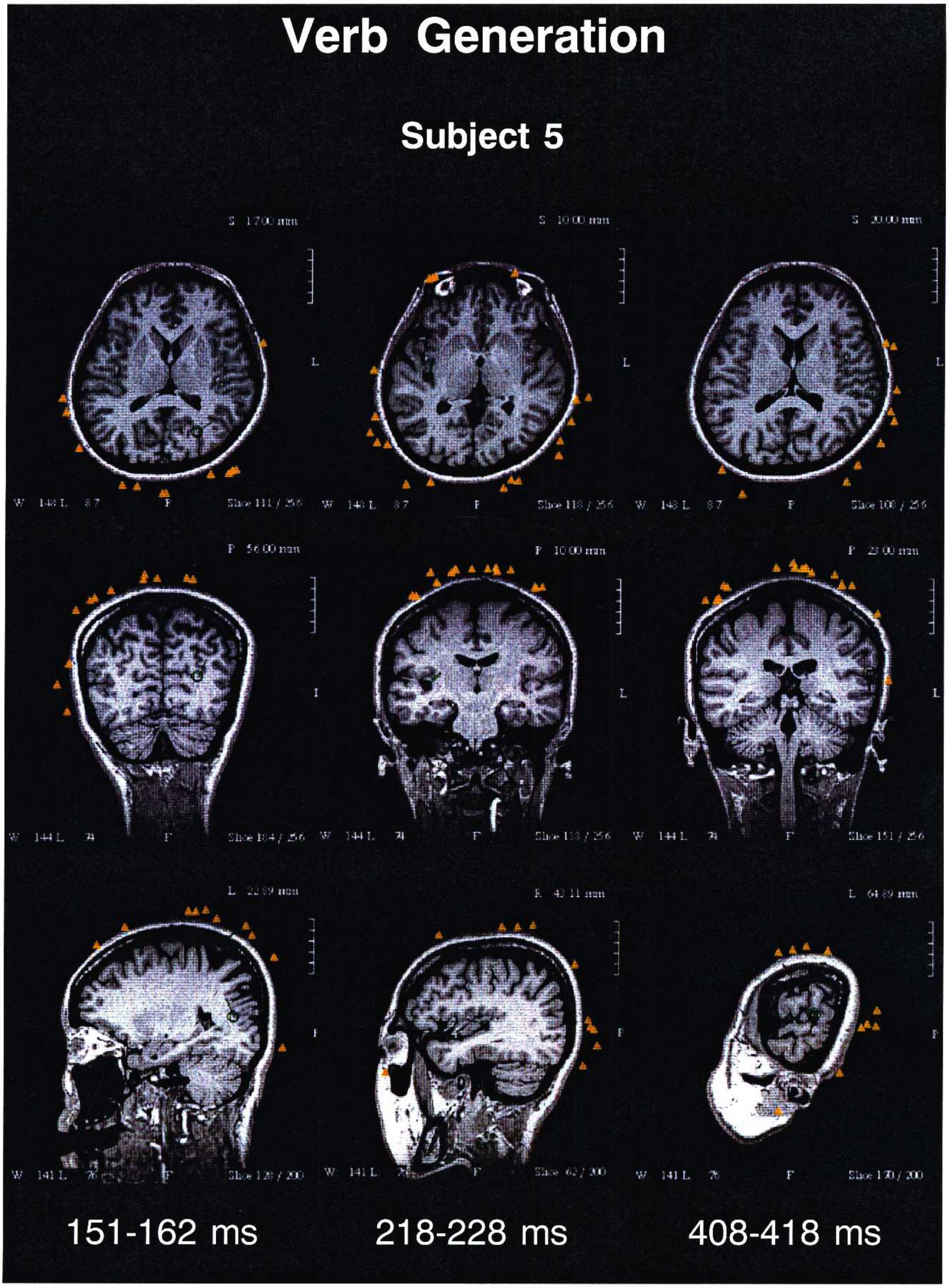


Fig. 4.51. Dipoles overlay on MR image of subject 5 in Verb Generation.

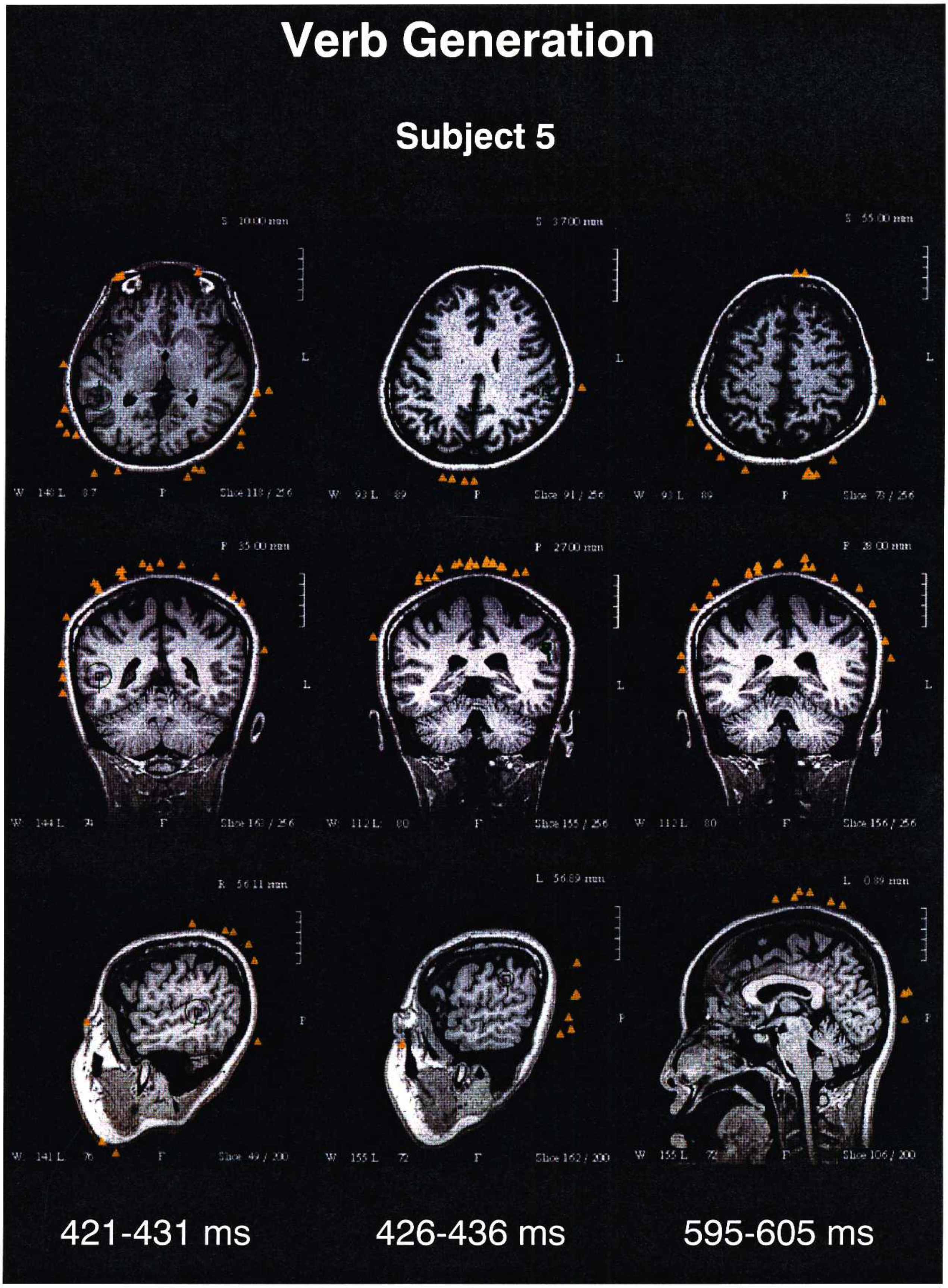


Fig. 4.52. Dipoles overlay on MR image of subject 5 in Verb Generation.

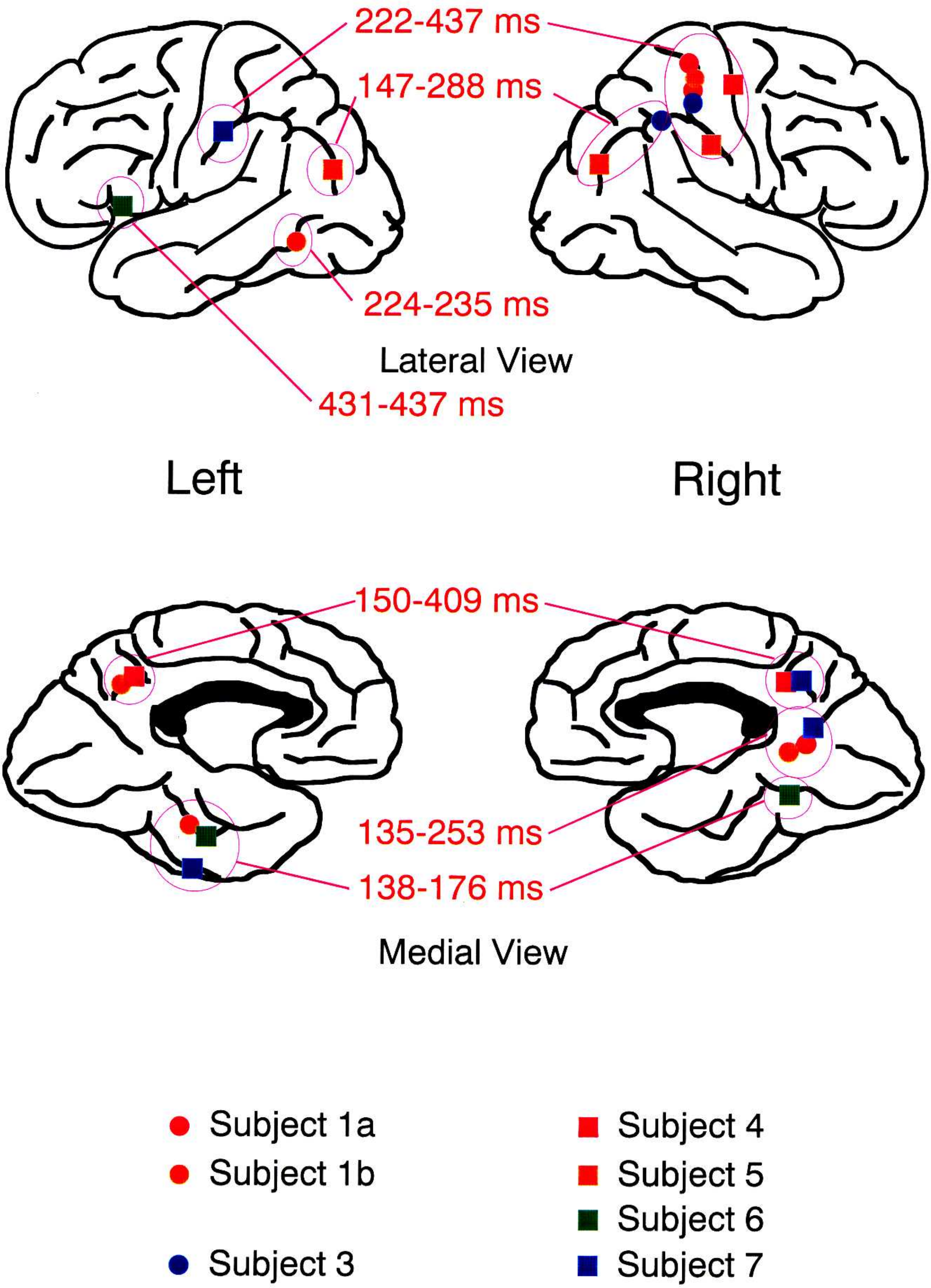


Fig. 4.53. Dynamic Activation in MEG word repetition experiment.

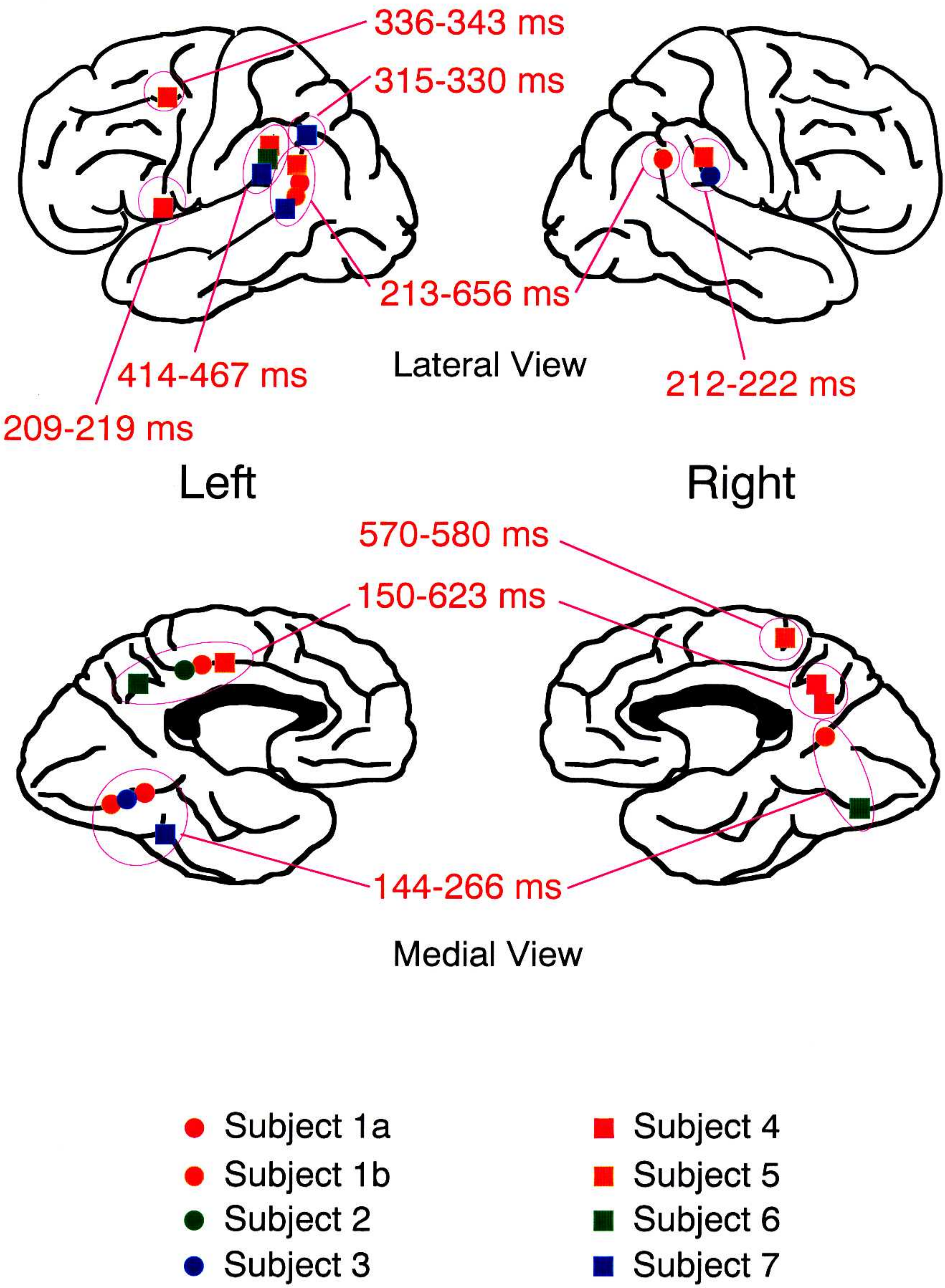


Fig. 4.54. Dynamic Activation in MEG randomized translation experiment.

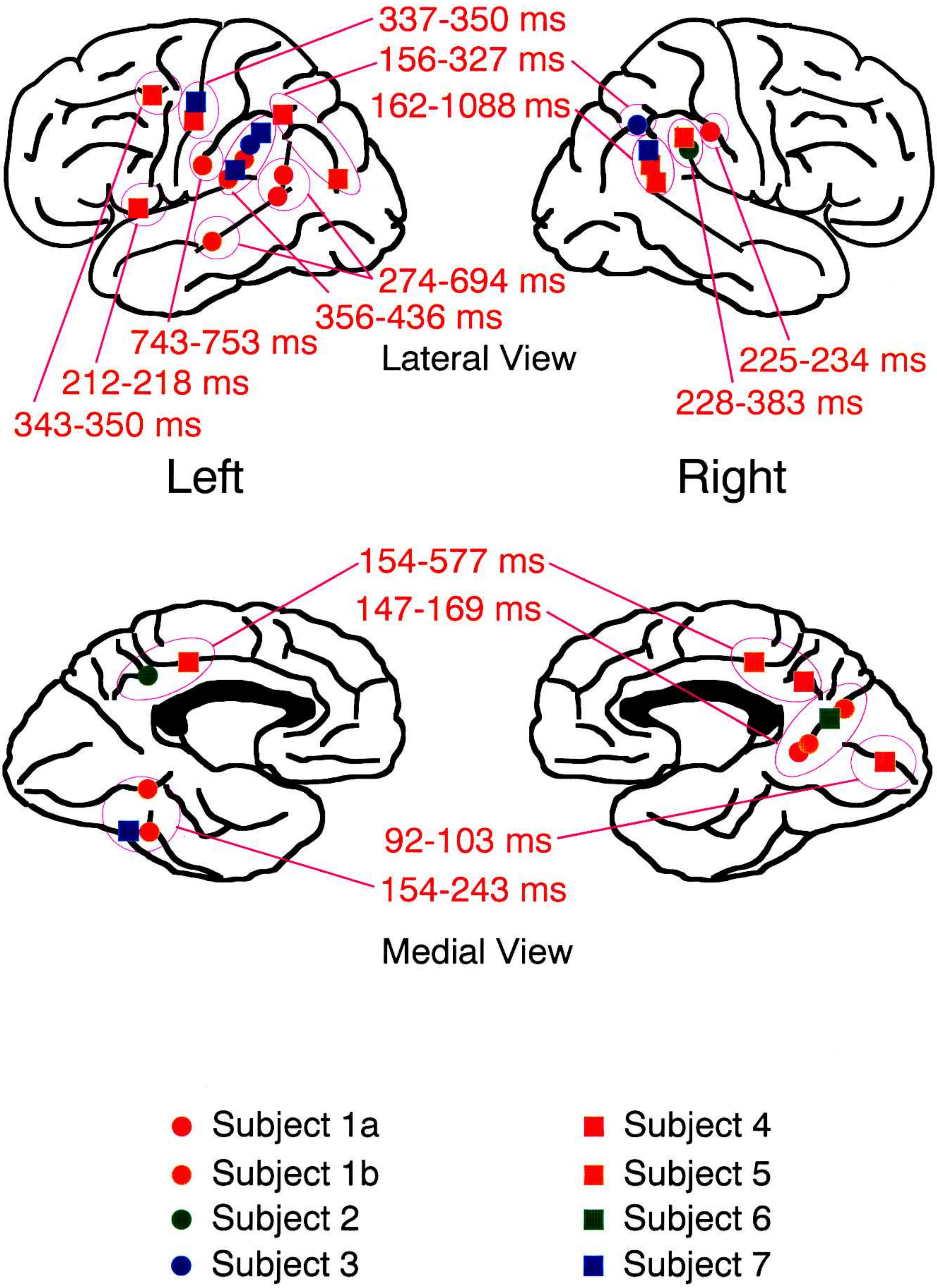


Fig. 4.55. Dynamic Activation in MEG categorized translation experiment.

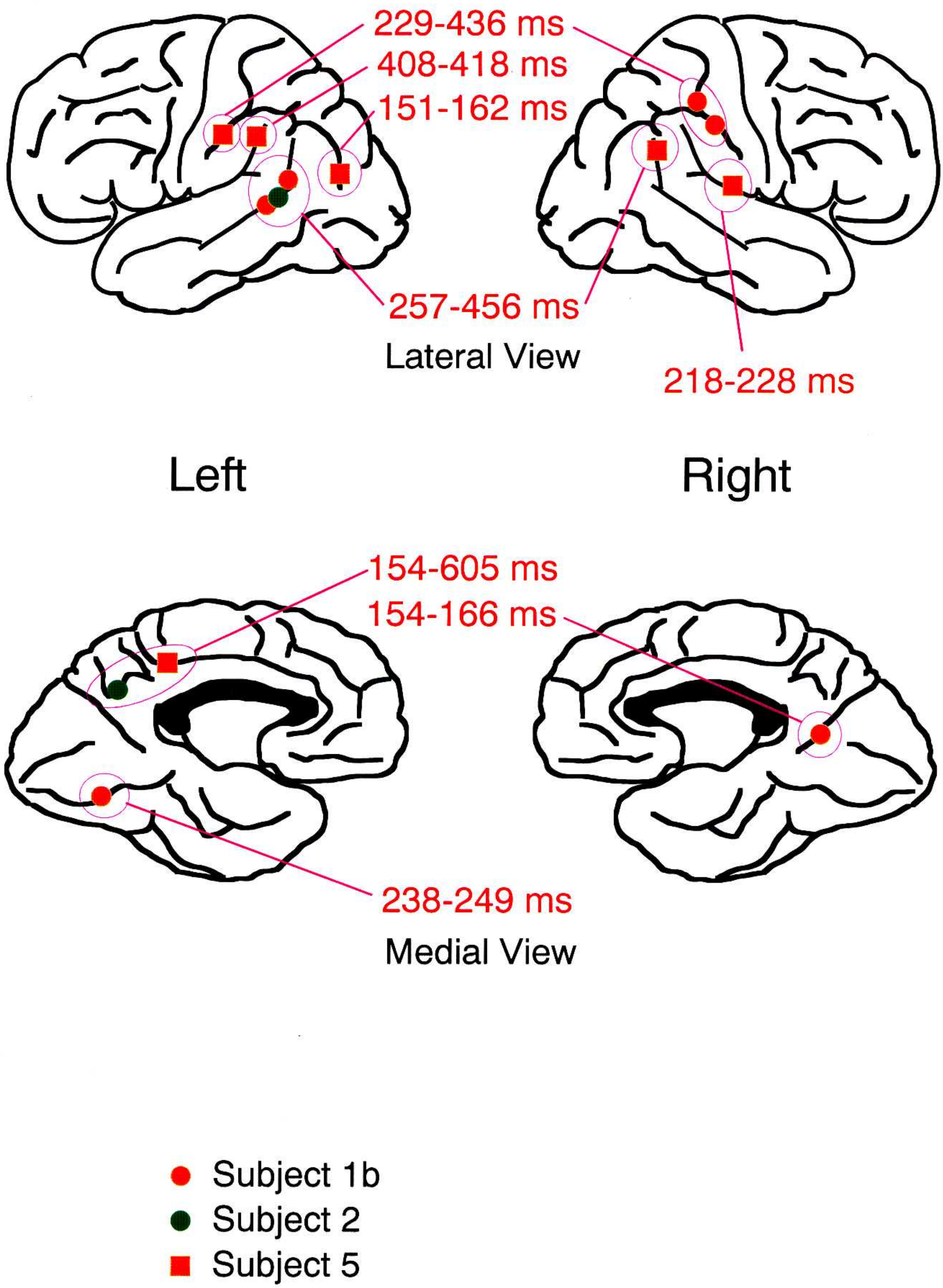


Fig. 4.56. Dynamic Activation in MEG noun-verb generation experiment.

4.4 Discussion

In general, activations observed in the right parieto-occipital sulcus (RPOS), left collateral sulcus (LCOS), left superior temporal sulcus (LSTS), left posterior lateral sulcus (LPLAS)(Wernicke's area) and bilateral posterior cingulate sulcus (PCIS) are consistent with the previous MEG studies on neural activities related to Japanese language using the similar MEG systems[16,27,28].

In MEG studies, activations of RPOS at latency 155-280 ms were observed when the Japanese subjects were stimulated by readable Japanese characters (Kana)[27,28]. On the other hand, the symbols[28], pseudo-characters[27,28] and words[28] did not activate this area. Thus, it implied that RPOS mediates the function that subserves early processing of only visual readable character of L1 in the present study.

Activations of the ventral path in the left fusiform gyrus and inferior temporal gyrus, which are adjacent to LCOS, were observed at latency 125-250 ms when the Japanese subjects were stimulated by pseudo-characters[27] and words[28] in MEG studies. Negative potentials near latency 200 ms (N200) of cortical event-related potentials (ERPs) in 27 right-handed patients indicated responded equally to words and non-words in the posterior fusiform gyrus[20]. A PET study in 10 Japanese subjects reading *kana* (Japanese Hiragana and Katakana) words and non-words indicated significant activation ($p < 0.01$) in the left posterior inferior temporal area[5,49]. Other PET studies in 16 and 10 non-Japanese subjects suggested that words activated the left fusiform gyrus[4,20]. On the other hand, pictures in PET[4] and MEG[50] studies, sentences, semantic priming words, pictures and patterns in a cortical ERPs study[35] did not activate this area. Therefore, it suggested that LCOS mediates the function that subserves processing of letter-strings (word-perception) of L1 in the present study.

The left supramarginal gyrus (LSMG)(Wernicke's area) was activated in several neuroimaging studies[46] : (1) PET studies in 16 subjects using word naming task[4], in 17 subjects using sensory task[40,41] and in 9 subjects using phonemes and word monitoring task[10], (2) an fMRI study in 30 subjects using semantic decision task of speech sound[3], and (3) an MEG study using phonemes matching task of readable Japanese characters[27]. These studies indicated consistently that LSMG may be related to phonological processes. In addition, an activation of the superior temporal gyrus including Wernicke's area was considered to be involved in phonological processing in an fMRI study using rhyme vs case decision task in 28 subjects[47]. In comparison to normal subjects, an fMRI using visual English sentences vs. consonant strings and American Sign Language sentences vs. nonsign tasks in congenitally deaf subjects demonstrated no significant activations in LSMG[34]. These fMRI studies also suggested the role of Wernicke's area in phonological processing which is consistent with the classical model in the role of Wernicke's area[19]. In the present study, more extensive activations in this area were observed in both randomized and categorized translation tasks than repetition task of visual words. Thus, the role of LPLAS in the present study, which is adjacent to LSMG, may related to phonological processing, probably, for phonological memories[3,41] of L2.

According to a PET study in 9 subjects using words-tones and words-phonemes comparison task, the angular gyrus (AG), which is adjacent to LSTS, may be related to lexico-semantic processes and not to phonological processes[10]. The other PET study using noun and verb generation task vs rest also suggested that the posterior part of LSTS may be involved in noun and verb retrieval[54]. In the present study, therefore, the role of LSTS may related to memory in word retrieval of L2.

Studies of event-related potentials in silent speech demonstrated significant differences of grand average potentials at electrode F_Z across 8 subjects at latency 420 ms[15] and across 6 subjects at latency 580 ms[17]. Equivalent dipoles estimated from an ERP study on silent speech[17] and an ERF study on silent reading of Japanese Katakana[16] suggested activations of the posterior cingulate sulcus (PCIS) at latency over 400 ms. From these previous studies, the function of PCIS was considered to be related to attention[15,16,17]. In the present study, more extensive activations in PCIS were observed in randomized translation task than in word repetition task with a wide latency range (150-600 ms). Thus, it suggested that PCIS may be involved in attention during the translation task.

In comparison to activations in word repetition experiment, increases of activations in LSTS and LPLAS were found in categorized and randomized translation experiments which suggested increase in demands for word retreival and phonological memory of L2.

Difference between categorized and randomized translation experiment was observed only in the right superior temporal sulcus (RSTS). Activation of RSTS may be increased by demand of searching for appropriate words in L2.

In comparison to word repetition, noun-verb generation experiment which involved L1 to L1 word generation, indicated increasing of activation in LSTS. This suggested the role of LSTS in word retreivals of both L1 and L2.

A possible reason that activation in the primary visual cortex (striate cortex) could not observe in the present study is the location of stimulus. Since a visual stimulus at the center of visual angle evokes the primary visual cortex in up right, up left, down right and down left parts, the evoked magnetic fields cancel each others giving very weak resulting fields.

Chapter 5

Conclusions

5.1 Findings from fMRI and MEG

1. Findings from fMRI

Significant brain areas related to L1-L2 translation were observed in (1) the left inferior frontal cortex including Broca's area and Insula, (2) bilateral prefrontal cortex, (3) bilateral supplementary motor areas, (4) left precentral cortex and (5) left intraparietal sulcus as shown in Fig. 5.1. The left hemispheres were significantly activated than the right hemispheres across subjects. Based on the aspect of language function, extensive activations in the left inferior frontal cortex and bilateral supplementary motor areas were thought to be related to semantic processing of both L1 and L2 and inner speech planning of L2, respectively.

2. Findings from MEG

In comparison to word repetition (control condition)(Fig. 5.2), estimated dipoles from randomized translation (Fig. 5.3), categorized translation (Fig. 5.4) and verb generation (Fig. 5.5) were observed in the right parieto-occipital sulcus (150-250 ms), left collateral sulcus (150-250 ms), left superior temporal sulcus (200-650 ms), left posterior lateral sulcus (Wernicke's area) (350-450 ms) and bilateral posterior cingulate sulcus (150-600 ms). Based on the aspect of language function, activations of the right parieto-occipital sulcus and left collateral sulcus, left superior temporal sulcus, left posterior lateral sulcus (Wernicke's area) were thought to be related to character recognition of L1, word recognition of L1, lexical retrievals of L2, phonological processing of L2, respectively.

3. Findings from integration of fMRI and MEG studies

Integration of findings from fMRI and MEG showed the brain areas and their functions involving L1 to L2 translation processes as shown in Fig. 5.6. MEG study suggested that the first process may be character and word recognitions of L1 in the right parieto-occipital sulcus and left collateral sulcus with a possibility of parallel processes in both areas due to the approximately same latencies of estimated dipoles. The second process may be a lexical retrieval of L2 in the left superior temporal sulcus with a possibility of multiple accesses during translation due to the observation of dipoles in wide range of latency. The third process may be a phonological processing of L2 in the left posterior lateral sulcus (Wernicke's area). FMRI study suggested that the left inferior frontal cortex and bilateral supplementary area may be related to a semantic processing of L2 and inner speech planning of L2, respectively. However, timing sequences of these areas were unknown due to lack of temporal information from fMRI experiment.

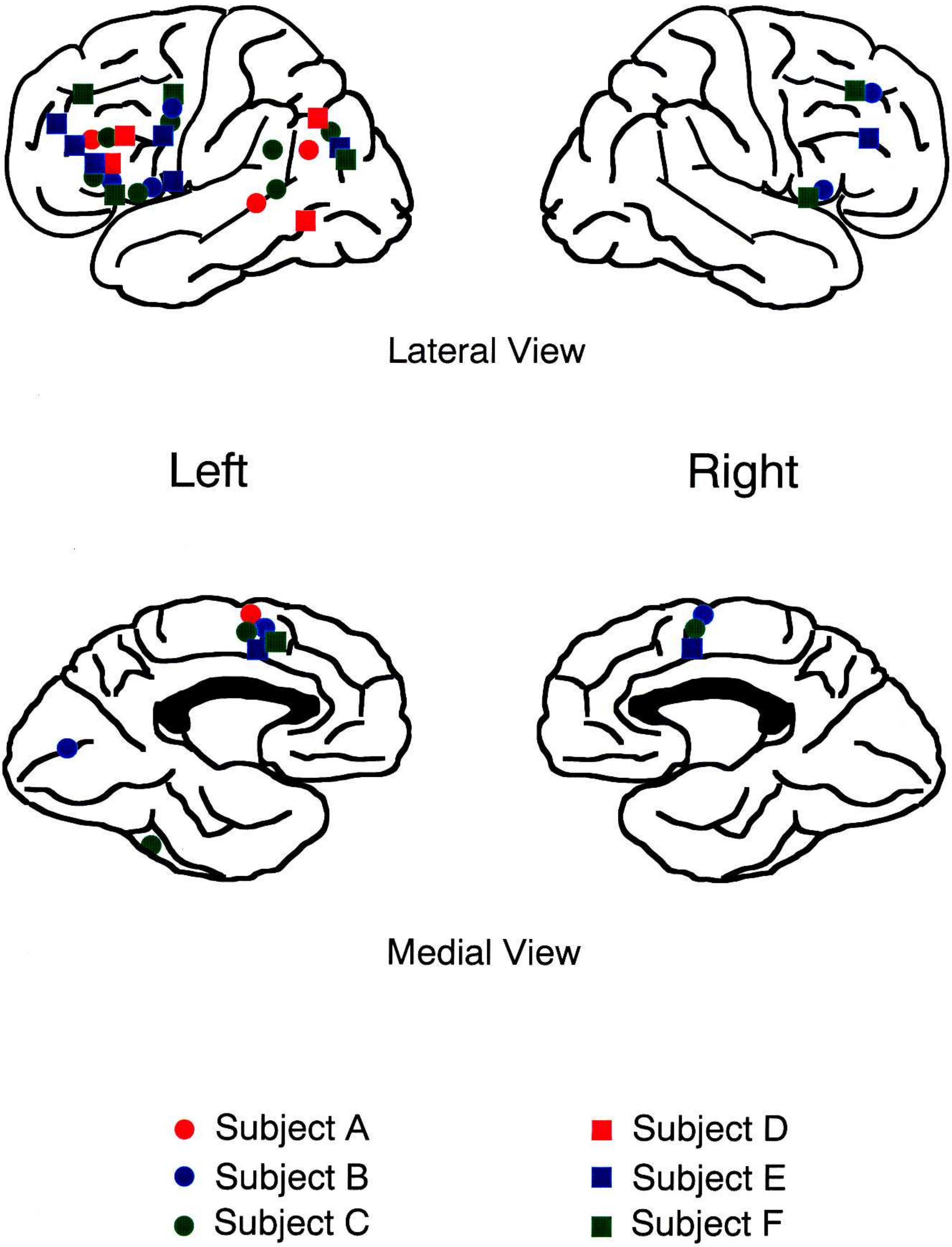


Fig. 5.1. Activated brain areas in fMRI randomized translation experiment.

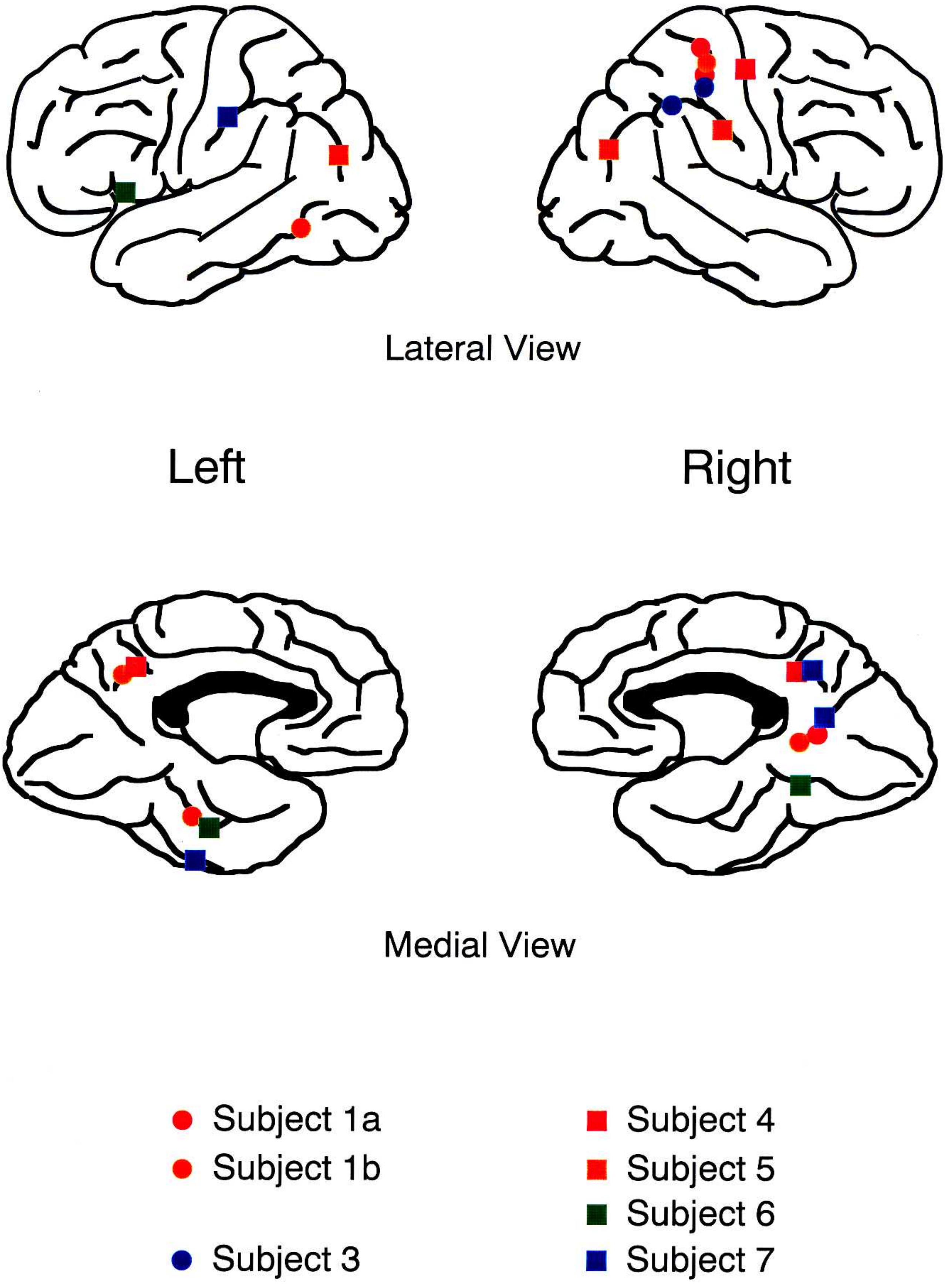


Fig. 5.2. Equivalent current dipoles in MEG word repetition experiment.

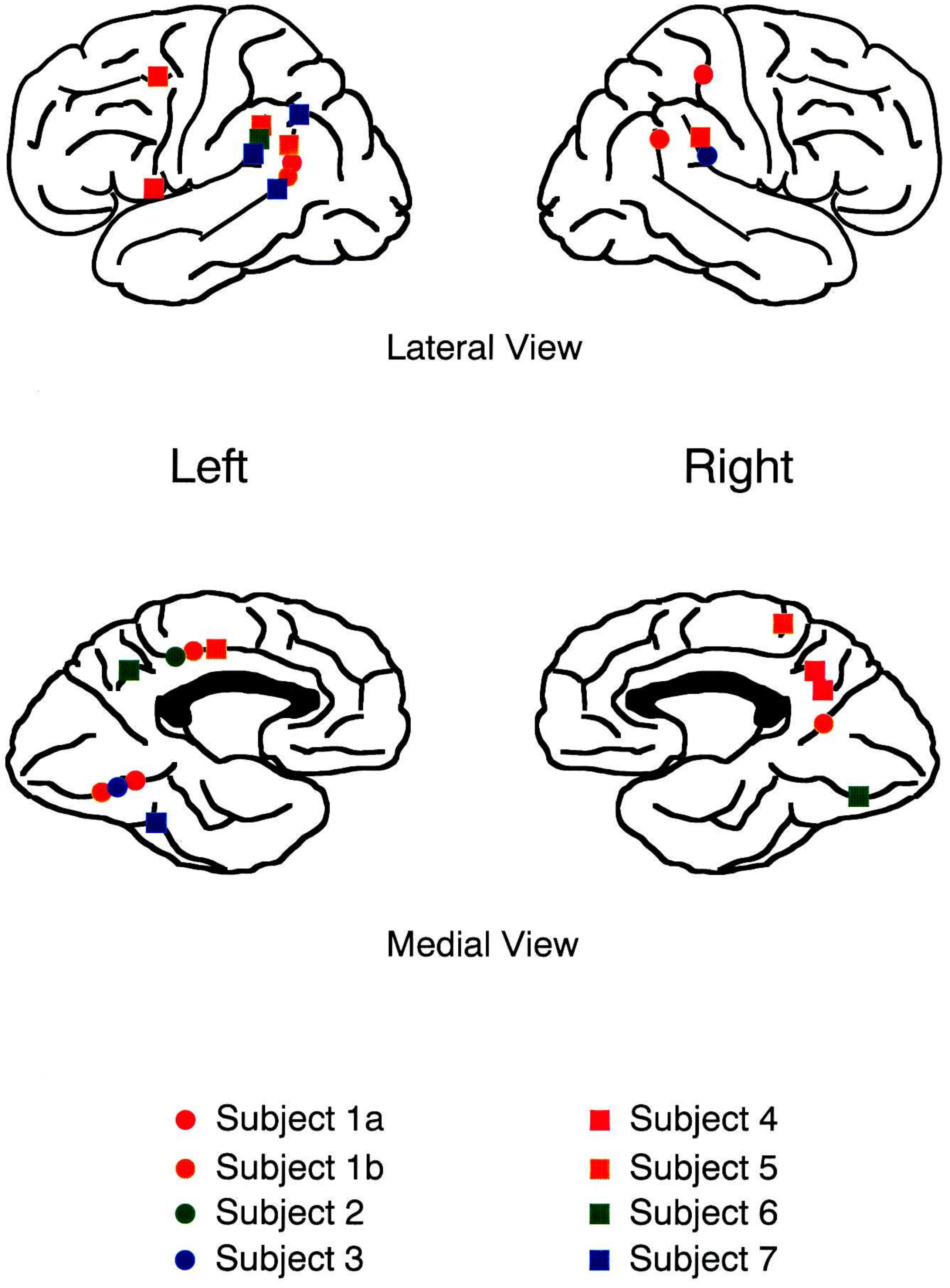


Fig. 5.3. Equivalent current dipoles in MEG randomized translation experiment.

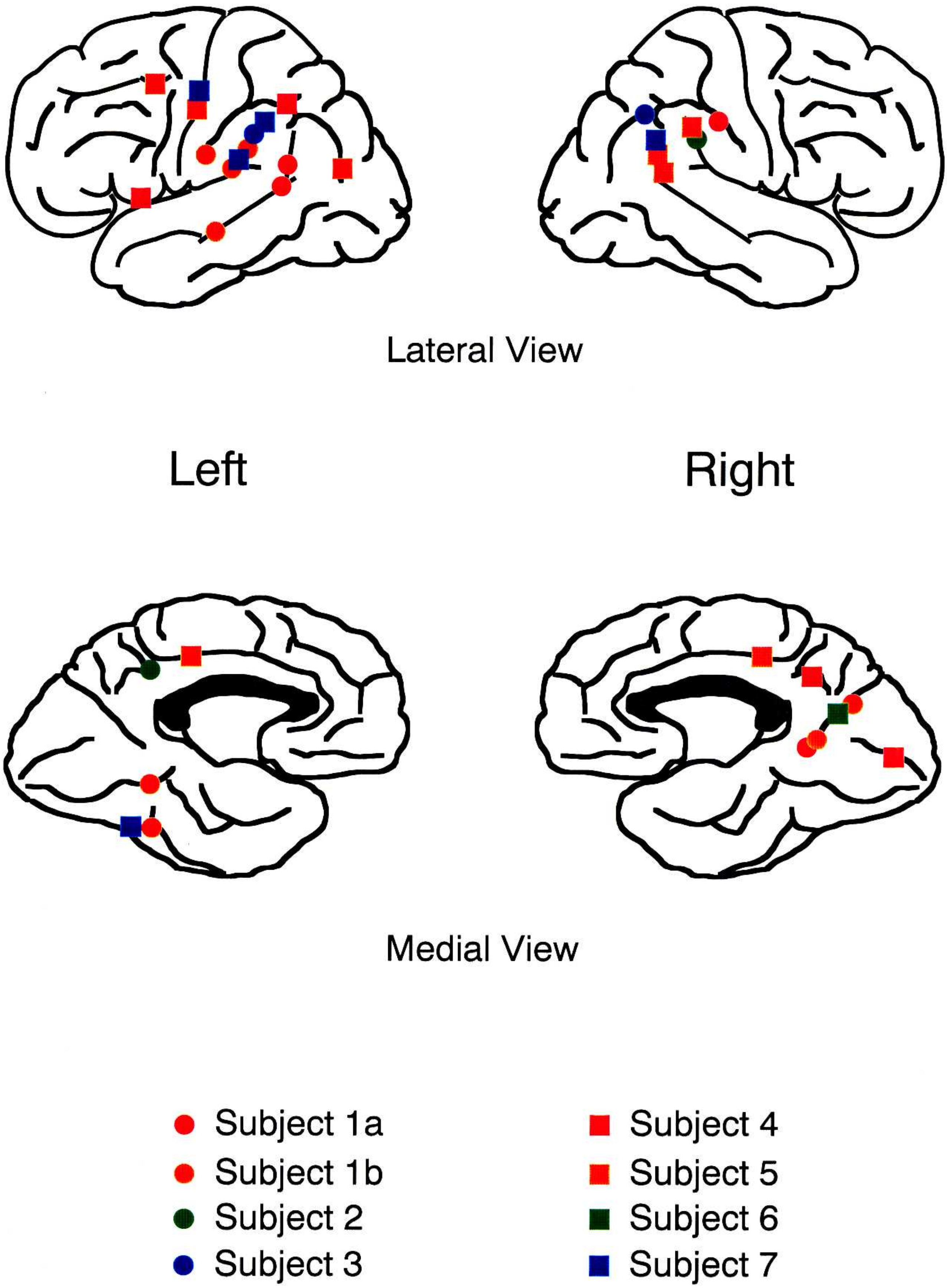


Fig. 5.4 . Equivalent current dipoles in MEG categorized translation experiment.

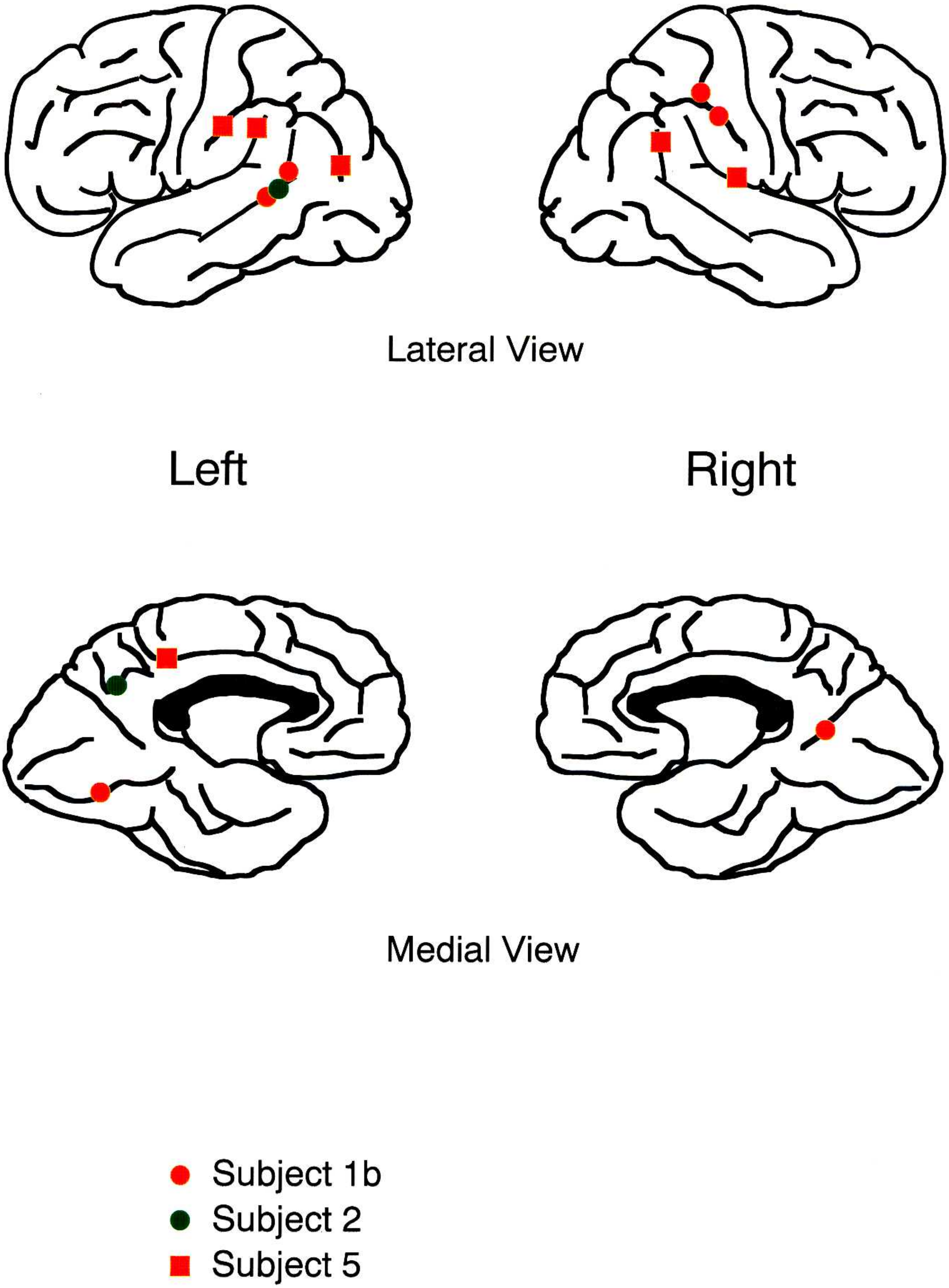


Fig. 5.5. Equivalent current dipoles in MEG noun-verb generation experiment.

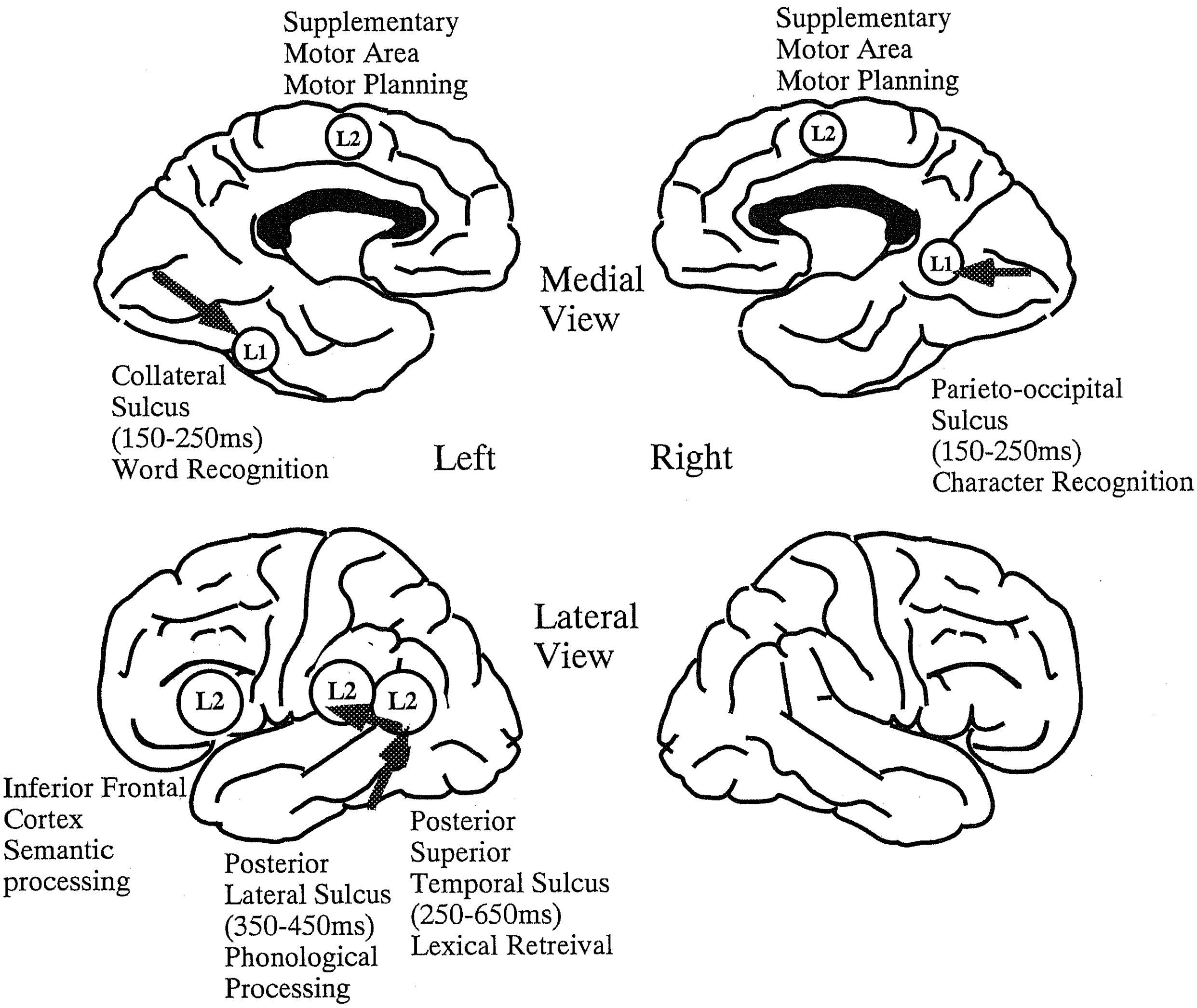


Fig. 5.6. Brain areas and functions which related to translation of L1 to L2 .

5.2 Discussion

The variance in sex[37], brain organizations[37], verbal abilities[37], physical and mental conditions may be considered as the factors that caused individual different activations across subjects in both fMRI and MEG studies.

A number of possibilities were considered to explain differences between fMRI and MEG results: (1) differences of MEG signals due to different kinds of neurons and different orientations of layers in the gray matter of different areas (Brodmann's areas), (2) unmeasurable MEG signals from stellate cells in the gray matter, (3) unmeasurable MEG signals in gyri, (4) cancellation of magnetic fields from parallel dipoles oriented in opposite directions, (5) large deviation of time to translate Japanese word, (6) weak MEG amplitudes in long latency (> 400ms), (7) algorithm errors of single dipole estimation in MEG study and (8) essential language areas seem to be focused in gyri and are rarely in sulci[37].

5.3 Remark

For fMRI, up to only 5% of signal changes in activated brain regions can detected by a clinical MR scanner (1.5T). Therefore, statistical analyses such as correlation coefficient, *t*-test,.etc. are essential tools for determining significant changes. Slice thickness is a necessary parameter to determine signal to noise ratio. Although, the more thickness provides the more signal to noise ratio, anatomical information is reduced. Interslice cross-talk can be reduced by insert a small gap between the scanning slices.

For MEG, activations in the prefrontal areas are difficult to detect. Reliability of algorithm to separate and localize multiple activations are not sufficient. Subject preparations, especially digitizing for the subject's head shape for experiment are time consuming.

Based on the present study, two possible applications were proposed: engineering and medical aspects. For engineering aspects, cognitive model and cortical activations of Japanese-English translation observed in the human brain suggested a novel approach for designing machine translator (MT). For medical aspects, not only brain regions related to L1 but also L2 should be included in pre-operation studies of bilingual patients before neurosurgery.

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