# Towards Unified Model of Spatio-Temporal Mental Orientation: Neurophysiological Correlates of Temporal Reference Point Function

TAKAHIRO SOSHI[†1, †2] SATOKO HISANAGA[†2]
KAORU SEKIYAMA[†2]

***Abstract***: Temporal mental orientation is a brain function that enables us to roam from the memorized past to the imaginable future. The neural correlates of temporal mental orientation, however, remain unclear. The present study performed a verbal experiment to investigate the neurophysiological correlates of temporal mental orientation. Neurophysiological activities were recorded extracranially, and we conducted time-domain and signal source estimation analyses. Right frontal positive and centro-parietal negative event-related brain potential amplitudes increased for the incorrect temporal orientation. Signal source estimation analysis demonstrated that these neural activities originated from the right precuneus, which functionally connected with the left premotor areas. Hence, the fronto-parietal functional connection contributes to temporal mental orientation.

***Keywords***: Mental orientation, Temporal reference point function, Natural language, Precuneus, Event-related potentials, Signal source estimation, Functional connectivity

## 1. Introduction

Temporal orientation is the mental ability to provide psychological ‘time-warping’ opportunities to free oneself from the present time and wander through memorized pasts and/or imaginable futures [1]. Such mental flexibility relies on a temporal reference point, which can change relative to the event and present (utterance) times [2,3]. The temporal reference point function is represented within natural language [3] and is exemplified by the change in interpretation of utterances, such as “De Lorean had come back at 0:00 a.m.” The first interpretation (the return at/around 0:00 a.m.) is obtained by the coincidence between the event and reference point times (0:00 a.m.) (**Fig.1**). Another interpretation (the return completed before 0:00 a.m.) is possible in terms of dissociation of the reference point time (0:00 a.m.) from the event time (before 0:00 a.m.). That is, a temporal reference point is not bound by the present and event times, but is verbally encoded from a subjective perspective, based on established rule constraints [3].

Previous neuroimaging studies have reported that mental orientation in the visuo-spatial dimension is related to increased hemodynamic responses in the posterior medial region of the parietal lobe (Brodmann area 7; BA 7) and the precuneus (PEc) [4]. Spatial orientation has been widely examined with a mental rotation paradigm using various objects, such as hands [5]. Our own body axis kinesthetically affects a person’s mental orientation of rotated hands, suggesting that a spatial reference point is robustly represented in the cortical network [6,7]. Although previous studies have reported that the neural correlates of the temporal orientation in individual memories (e.g., retrieval of past events and imagination of future events) are located in several cortical areas, such as the prefrontal and parietal areas [8], the neural correlates of the temporal reference point function as well as related biological constraints have not been yet investigated.

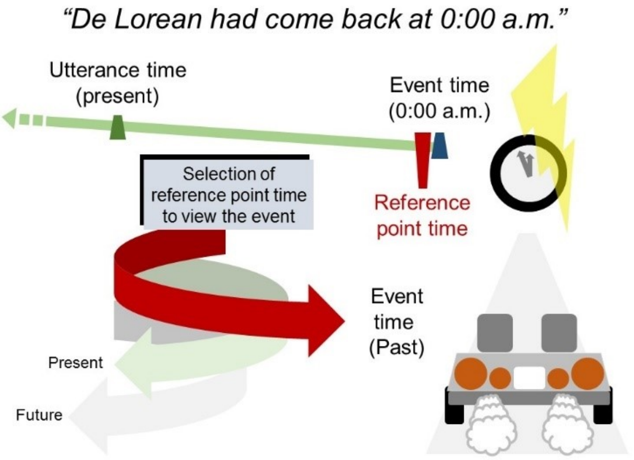

**Fig. 1** Temporal reference point function: is associated with the ordered relation among the event, utterance, and reference point times. The event and utterance times are objectively determined based on a physical clock time, and cannot change arbitrarily. The reference point time, on the other hand, changes relative to the event and utterance times due to a subjective temporal perspective of an event under cognitive constraints. This example generates the interpretation of the return at 0:00 a.m. based on coincidence of the event and reference times.

We recorded neurophysiological activity that was synchronized with the temporal reference point function. Verbal stimuli with correct or incorrect settings were prepared, and the synchronized neurophysiological signals [event-related potentials (ERPs)] were compared between conditions. We estimated the cortical sources for the temporal reference point function with the standardized low-resolution brain electromagnetic tomography (sLORETA) [9] and examined the functional connectivity between the cortical sources.

---

†1 National Center of Neurology and Psychiatry. †2 Kumamoto University

## 2. Methods

### 2.1 Participants

Eight healthy Japanese participants participated in the experiment (3 females, 5 males; age: mean ± sd, 21 ± 2 years old). They were right-handed (laterality quotient: 0.91 ± 0.11) [10] with normal or corrected-to-normal visual acuity. They possessed an ordinary short-term verbal memory span (reading span: 3.6 ± 1.2) [11]. They reported no physical or psychiatric illness, nor did they have any history of cortical damage from trauma. Based on the procedures approved by the local Human Subjects Ethics Committee, all participants provided informed consent before participation.

### 2.2 Experimental conditions and stimuli

The experimental conditions included two types of causal expressions with either correct future or incorrect past orientations, with each consisting of a main and subordinate clause. In the correct causal condition (**Fig. 2A**), the causal clause marker '-node' ("because") sets a temporal reference point to a non-past temporal point, based on the tense of the verb 'mosu' ("burn"). Therefore, pairs of the future adverb 'ashita' ("tomorrow") and the non-past verb are congruent. In the incorrect causal condition (**Fig. 2B**), the causal marker also sets a temporal reference point to a non-past time point, based on the verb tense; consequently, the past adverb 'kinou' ("yesterday") is incongruent with the non-past verb.

A control condition was also prepared. The two types of sentences included correct future (**Fig. 2C**) and correct past (**Fig. 2D**) orientations in temporal subordinate clauses. Japanese languages allow co-occurrence of non-past verbs and past adverbs in temporal clauses, because the temporal clause marker '-toki' ("when") can arbitrarily set a temporal reference point [12]. Each condition included 30 sentences, for a total of 120 sentences.

### 2.3 Procedure

The participants faced a 19-inch display 1 m in front of their heads, and judged the acceptability of sentences with 'yes' or 'no' responses after reading all six words. Each word was visually presented with white font in the center of a black background with stimulus duration ranging from 200 to 500 ms, with a fixed stimulus-onset-asynchrony of 800 ms. The four experimental conditions were equally divided into the six blocks (5 sentences × 4 conditions in each block) and were presented randomly.

### 2.4 Neurophysiological recording and analyses

Electroencephalograms (EEG) were continuously recorded with a 1,000 Hz sampling rate, and were amplified by the band-pass frequencies from DC (0 Hz) to 100 Hz (NuAmps40; Compumedics Neuroscan, Compumedics Neuroscan, Inc., Charlotte, NC). EEGs were recorded from 30 Ag/AgCl sintered scalp electrodes that were placed equidistantly on the elastic cap with the extended 10-20 system. Three electrodes were placed around the eyes to record horizontal and vertical electro-oculograms for monitoring artifacts. All electrodes were referenced to the linked mastoids. The ground electrode was positioned on AFz. The impedance was set below 5,000 Ω throughout the recording.

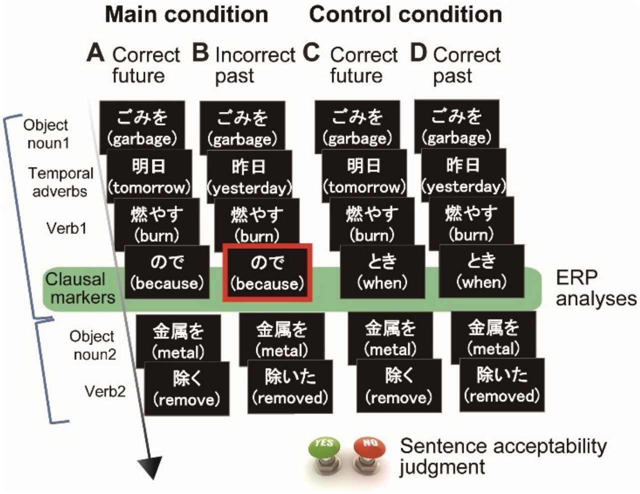

**Fig. 2** Experimental conditions. Each stimulus visually appeared with a stimulus-onset-asynchrony of 800 ms. The participants judged the acceptability of the sentences. Neurophysiological responses to the clausal markers associated with a temporal reference point function are compared within each condition (main: **A** versus **B**; control: **C** versus **D**).

Recorded EEGs were filtered offline with a band-pass filter from 0.3 to 40 Hz (FIR filter, 24 dB/octave, zero-phase shift) and were segmented into epochs from 100 ms before the onset of clausal markers to 700 ms after onset, for each condition (30 epochs). Individual averaged waveforms were calculated after baseline correction (mean potentials from −100 to 0 ms) and artifact rejection of residual artifacts (peak-to-peak amplitudes: ±75 μV). The mean rejection rate for each epoch was about 10%. Grand averaged ERP waveforms were smoothened using a moving average filter (21 data points) for ease of visual inspection and were compared between the two types of temporal orientations for the main and reference conditions. EEG data recording and analysis were performed using Scan 4.3 software (Compumedics Neuroscan, Inc., Charlotte, NC).

sLORETA was used to estimate the neural sources of the observed ERP effects. This inverse signal source estimation method provides a rough three-dimensional resolution of neural sources by maximally avoiding localization errors at the expense of high spatial resolution [9]. sLORETA presupposes that synchronization of adjacent neural populations takes place for information processing, and solves the inverse problem to find the smoothest solution in orientation and strength of source grid points, that is, low spatial resolution. The spatial resolution was 6,239 voxels (voxel size: 5 mm × 5 mm × 5 mm), and source estimation was made only from the cortical gray matter and hippocampus [13].

## 3. Results

### 3.1 Time-domain analysis

We compared the two temporal orientations separately for the main and control conditions with a 100 ms interval. The poststimulus time window from 300 to 600 ms was specified as the temporal region of interest because this time window has been

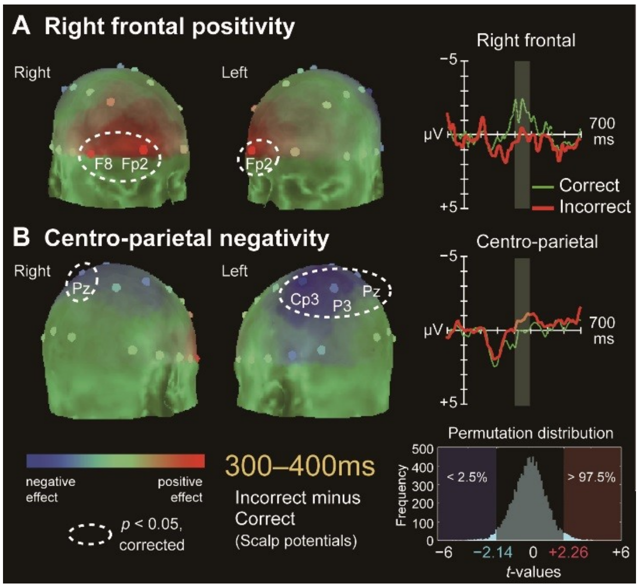

**Fig. 3** Scalp event-related potential effects for incorrect temporal orientation in the main causal condition. Right anterior frontal positive (**A**) and centro-parietal negative (**B**) potential effects are observed for incorrect temporal orientation, compared to correct orientation. The white circles represent electrode clusters that are significant at a corrected α level of $p < 0.05$, corrected. The permutation distribution of dummy t-values ($n = 10{,}000$) possess the 95% confidence interval ranging from −2.139 to 2.261, and is plotted below the brain potential waveforms.

widely recognized in major verbal processing [14]. A multi-electrodes cluster comprising more than one significant electrodes ($p < 0.05$) will be reported as a robust neural activation. Since we recorded data from a small number of participants, we conducted non-parametric permutation paired t-tests. Permutation tests are also effective to avoid type I errors resulting from multiple tests [15]. The overall samples were first randomized [2 conditions (main, control) × 2 types (future, past) × 30 electrodes × 7 time windows × 8 participants], and the re-sampled paired data (8 participants × 2 types) were compared 10,000 times with paired t-tests. The actual t-values that were outside the 95% confidence interval (CI) of the permutation distribution of the dummy t-values were considered significant at a corrected level of $p < 0.05$. We obtained the 95% CI ranging from −2.139 to 2.261 (**Fig. 3**).

The incorrect past orientation in the main condition increased the positive voltages in the right anterior frontal scalp regions (**Fig. 3A**), and increased the negative voltages in the centro-parietal regions during the interval from 300 to 400 ms (**Fig. 3B**). Centro-parietal (CP3, P3, Pz) and right anterior frontal (Fp2, F8) multi-electrode clusters yielded supra-threshold effects (CP3, $t = -3.030$; P3: $t = -2.216$; Pz: $t = -2.146$; Fp2: $t = 3.147$; F8: $t = 2.712$; all of ps $< 0.05$, corrected). In the control condition, robust significant differences were not found in the multiple electrodes.

### 3.2 Signal source analysis

Using sLORETA and the non-parametric permutation

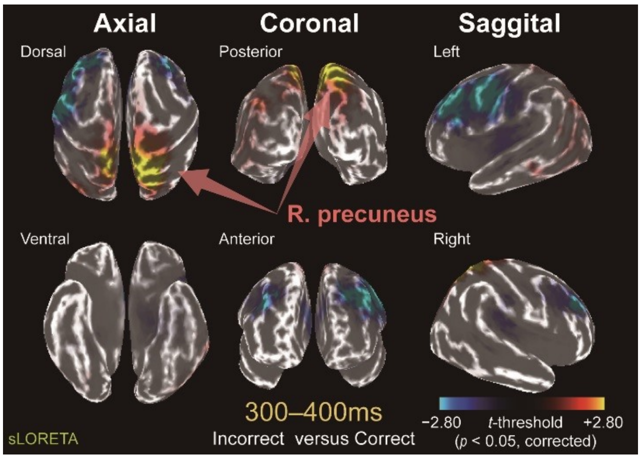

**Fig. 4** Cortical sources of scalp potential effects for incorrect temporal orientation in the causal condition, estimated by sLORETA. Right (R) precuneus enhances activation for incorrect temporal orientation (**Fig.1B**), compared to correct orientation (**Fig.1A**).

procedure, we next estimated the neural correlate origins within a fixed gray-matter volume for each of the correct future and the incorrect past temporal orientations in the main causal condition (6,239 voxels, which was equal to the number of re-sampled data in the permutation test). We then calculated the current source densities for the incorrect and correct conditions from the average scalp potentials (300-400 ms) for each participant and compared the source activities between the two conditions at the voxel level with permutation t-tests [16]. We obtained the ten significant clusters (> 5 voxels) with supra-threshold neural activities (two-tailed t-threshold of $> |2.81|$, $p < 0.05$, corrected).

Increased source activities for incorrect temporal orientation were observed on the right side PEc [BA 7 (26 voxels): t-values $> |2.82|$, $p < 0.05$], the superior parietal [BA 7 (19 voxels): t-values $> |2.92|$, $p < 0.05$], postcentral [BA 5 (8 voxels): t-values $> |2.86|$, $p < 0.05$; BA 7 (8 voxels): t-values $> |2.96|$, $p < 0.05$], and paracentral [BA 5 (17 voxels): t-values $> |2.81|$, $p < 0.05$] areas (**Fig. 4**). In contrast, decreased source activities for incorrect temporal orientation were localized to the frontal regions, including the left middle frontal [BA 6 (9 voxels): t-values $> |2.91|$, $p < 0.05$; BA 8 (9 voxels): t- values $> |2.82|$, $p < 0.05$; BA 9 (28 voxels): t-values $> |2.81|$, $p < 0.05$], the left precentral [BA 6 (28 voxels): t-values $> |2.81|$, $p < 0.05$], and the right middle frontal [BA 9 (8 voxels): t-values $> |2.93|$, $p < 0.05$] areas.

### 3.3 Functional connectivity

Based on previous findings, the PEc establishes extra-parietal cortico-cortical connectivity with the frontal areas [6,15]. We therefore defined the right PEc's 26-voxel cluster as a seed, then performed permutation analyses for correlations between the right PEc and the precentral (BA 6), or frontal (BA 6, 8, 9) areas (82 voxels). Dummy paired data (8 participants × 2 locations) were re-sampled from overall samples (108 voxels × 8 persons), and were repeatedly correlated with each other (26 PEc's voxels × 82 voxels in other areas = 2,132 times). We obtained the 95%

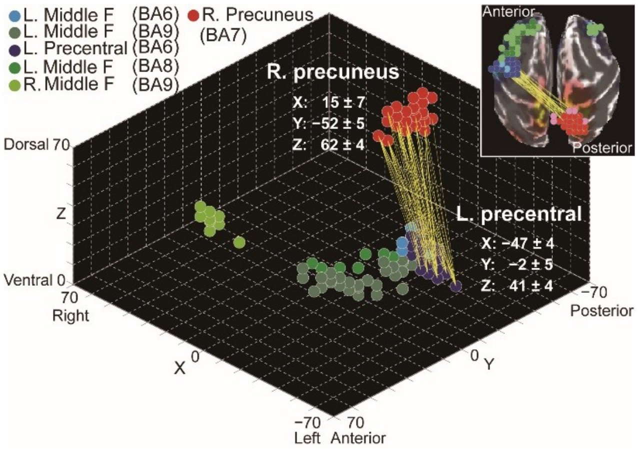

**Fig. 5** Functional connectivity for incorrect temporal orientation in the main causal condition between the right (R) precuneus (BA 7) and left (L) precentral (BA 6) areas. The right precuneus is positively correlated with the left precentral area (Pearson's rs > 0.7).

CI of the permutation distribution of dummy coefficients (Pearson's r: −0.726 to 0.683). Fourteen voxels from the 26 voxels in the right PEc (Talairach coordinates: mean ± sd, x = 15 ± 7 mm; y = −52 ± 5 mm; z = 62 ± 4 mm) correlated positively with the 8 voxels in the left precentral area (BA 6: x = −47 ± 4; y = −2 ± 5; z = 41 ± 4) [observed r-values (n = 55): mean ± sd, 0.72 ± 0.03, $p < 0.05$, corrected] (**Fig. 5**).

## 4. Discussion

The present study aimed to investigate the neural correlates and functional connectivity underlying temporal mental orientation, using human extracranial EEG recordings. We compared two types of clausal markers related to temporal reference point functions. The causal marker '-node' ("because") does not allow a flexible setting of a temporal reference point, while the temporal marker '-toki' ("when") does allow a flexible temporal reference point setting. We observed robust centro-parietal electric signals for incorrect temporal orientation in the causal condition. The right precuneus was related to these local potentials and was functionally connected with the left precentral areas.

The right precuneus, based on the fronto-parietal cortico-cortical network, may contribute to a temporal reference point function. A previous neuroimaging study that used a visual imaginary task in which the participants imaged past or future events reported that temporal mental orientation activates several cortical areas, including the right precuneus (x = 6; y = −53; z = 57) [8]. This cortical coordinate is adjacent to the coordinate of the activation location of the right precuneus in the present study. The functional overlapping in the right precuneus between the present and previous studies is summarized in **Fig. 6**. The mean 3D coordinates of the right precuneus in the present study (x = 15; y = −52; z = 62) are adjacent to those in the previous visuo-spatial (e.g., a mental rotation: x = 10; y = −64; z = 53) and temporal memory (e.g., an episodic memory retrieval: x = 7; y = −67; z = 37) tasks. The precuneus is anatomically connected to the dorsal premotor and precentral areas [17,18]. It has also been functionally reported that not only the right parietal area (x = 24; y = −68; z = 48), but also the left precentral area (x = −32; y = −4; z = 44) are activated during spatial mental orientation of rotated abstract figures [19]. The 3D location of this precentral area is adjacent to the left precentral areas in the present study (BA 6: x = −47 ± 4; y = −2 ± 5; z = 41 ± 4). Hence, fronto-parietal functional connectivity is likely associated with mental orientation based on spatial and temporal reference points. Taken together, modality-independent mental orientation may be associated with the right precuneus, which suggests the requirement to establish a unified neural coding model of mental orientation per se.

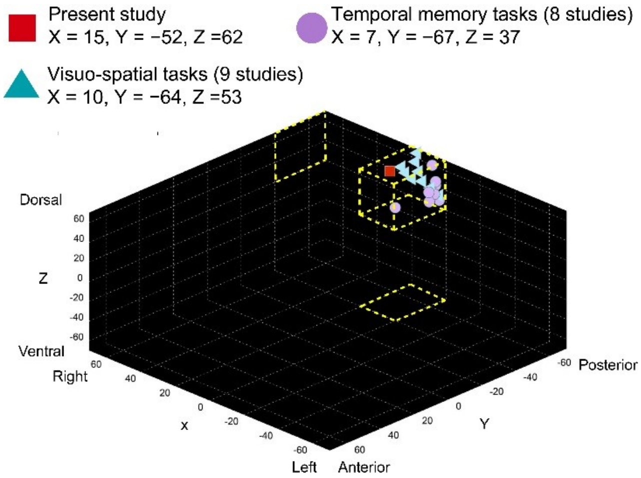

**Fig. 6** Functional overlapping in the right precuneus between spatial and temporal orientation tasks. The present cortical activation (red square) in the right precuneus is observed adjacently to the activation areas in the previous visuo-spatial (blue triangle) and temporal memory (purple circle) tasks.

## 5. Conclusion

The present study demonstrated that human extracranial EEG recordings during temporal reference point processing activated the right precuneus, which was functionally connected to the left precentral area. Future studies should explore an information processing model for spatio-temporal mental orientation.

**Acknowledgments** This study is the modified version of the study which has been published in IPSJ Transactions Bioinformatics Vol.9 (pp.12−17). This study is supported by Grant-in-Aid for Challenging Exploratory Research from the Japan Society for the Promotion of Science (No. 15K12884). The authors have no conflict of interest declared. We sincerely express our gratitude to the late Prof. Hiroko Hagiwara (Dept. Language Sciences, Tokyo Metropolitan University) and Prof. Shingo Tokimoto (Mejiro University).

## References

[1] Itoh, S., and Goto, N.: Suddendorf, T., and Busby, J.: Mental time travel in animals? *Trends. Cogn. Sci.*, Vol.7, No.9, pp.391−396. DOI:10.1016/S1364-6613(03)00187-6 (2003).

[2] Reichenbach, H.: Elements of Symbolic Logic, The Macmillan Co., New York, (1947).

[3] Hornstein, N.: As Time Goes By: Tense and Universal Grammar, The MIT Press, Massachusetts, (1990).

[4] Oshio, R., Tanaka, S., Sadato, N., Sokabe, M., Hanakawa, T., and Honda, M.: Differential effect of double-pulse TMS applied to dorsal premotor cortex and precuneus during internal operation of visuospatial information, *Neuroimage*, Vol.49, No.1, pp.1108−1115, DOI: 10.1016/j.neuroimage.2009.07.034 (2010).

[5] Parsons, L.M.: Imagined spatial transformations of one's hands and feet, *Cogn. Psychol.*, Vol.19, No.2, pp.178−241. DOI:10.1016/ 0010-0285(87)90011-9 (1987).

[6] Sekiyama, K.: Kinesthetic aspects of mental representations in the identification of left and right hands, *Percep. Psychophys.*, Vol.32, No.2, pp.89−95. DOI:10.3758/bf03204268 (1982).

[7] Sekiyama, K., Kinoshita, T., and Soshi, T.: Strong biomechanical constraints on young children's mental imagery of hands, *R. Soc. Open Sci.*, Vol.1, 140118 (online), DOI:10.1098/rsos.140118 (2014).

[8] Nyberg, L., Kim, A.S., Habib, R., Levine, B., and Tulving, E.: Consciousness of subjective time in the brain, *Proc. Natl. Acad. Sci. U. S. A.*, Vol.107, No.51, pp.22356−22359, DOI:10.1073/pnas. 1016823108 (2010).

[9] Pascual-Marqui, R.D., Michel, C.M., and Lehmann, D.: Low resolution electromagnetic tomography: a new method for localizing electrical activity in the brain, *Int. J. Psychophysiol.*, Vol.18, No.1, pp.49−65, DOI:10.1016/0167-8760(84)90014-X (1994).

[10] Oldfield, R.C.: The assessment and analysis of handedness: the Edinburgh inventory, *Neuropsychologia*, Vol.9, No.1, pp.97−113 (1971).

[11] Daneman, M., and Carpenter, P.A.: Individual differences in working memory and reading, *J. Verb. Learn. Verb. Behav.*, Vol.19, pp.450−466 (1980).

[12] Yoshida, K.: A suggestion about teaching so-called past tense form "-ta" in noun modifier clause "toki" *Bulletin of International Student Center Yokohama National University*, Vol.8, pp.19−64 (online), http://hdl.handle.net/10131/1185 (2001).

[13] Pascual-Marqui, R.D., Esslen, M., Kochi, K., and Lehmann, D.: Functional imaging with low-resolution brain electromagnetic tomography (LORETA): a review, Methods Find. *Exp. Clin. Pharmacol.*, Vol.24, Suppl.C, pp.91−95 (2002).

[14] Friederici, A.D.: Towards a neural basis of auditory sentence processing, *Trends Cogn. Sci.*, Vol.6, No.2, pp.78−84, DOI:10.1016/S1364-6613(00)01839-8 (2002).

[15] Kimura, M., Ohira, H., and Schröger, E.: Localizing sensory and cognitive systems for pre-attentive visual deviance detection: an sLORETA analysis of the data of Kimura et al. (2009), *Neurosci. Lett.*, Vol.485, No.3, pp.198−203, DOI: 10.1016/j.neulet. 2010.09.011 (2010).

[16] Nichols, T.E., and Holmes, A.P.: Nonparametric permutation tests for functional neuroimaging: a primer with examples, *Hum. Brain. Mapp.*, Vol.15, No.1, pp.1−25, DOI:10.1002/hbm.1058 (2002).

[17] Cavanna, A.E., and Trimble, M.R.: The precuneus: a review of its functional anatomy and behavioural correlates, *Brain*, Vol.129, No.3, pp.564−583, DOI: 10.1093/brain/awl004 (2007).

[18] Goldman-Rakic, P.S.: Topography of cognition: parallel distributed networks in primate association cortex, *Ann. Rev. Neurosci.*, Vol.11, pp.137−156 (1988).

[19] Jordan, K., Heinze, H.J., Lutz, K., Kanowski, M., and Jäncke, L.: Cortical activations during the mental rotation of different visual objects, *Neuroimage*, Vol.13, No.1, pp.143−152, DOI:10.1006/ nimg.2000.0677 (2001).