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Analysis of Mutual Information Content for EEG Responses to Odor Stimulation for Subjects Classified by Occupation

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Abstract

To investigate the changes of cortico-cortical connectivity during odor stimulation of subjects classified by occupation, the mutual information content of EEGs was examined for general workers, perfume salespersons and professional perfume researchers. Analysis of the averaged-cross mutual information content (A-CMI) from the EEGs revealed that among the professional perfume researchers changes in the A-CMI values during odor stimulation were more apparent in the frontal region of the brain, while for the general workers and perfume salespersons such changes were more conspicuous in the overall posterior temporal, parietal and frontal regions. These results indicate that the brains of professional perfume researchers respond to odors mainly in the frontal region, reflecting the function of the orbitofrontal cortex (OFC) due to the occupational requirement of these subjects to discriminate or identify odors. During odor stimulation, the perfume salespersons, although relatively more exposed to odors than the general workers, showed similar changes to the general workers. The A-CMI value is in inverse proportion to psychological preferences of the professional perfume researchers and perfume salespersons, though this is not the case with the general workers. This result suggests that functional coupling for people who are occupationally exposed to odors may be related to psychological preference.

Key words: different occupation, frontal, temporal, posterior parietal regions, functional connectivity, mutual information content, odor stimulation, psychological preference

Introduction

A variety of electrophysiological techniques, such as the electroencephalogram (EEG), chemosensory event-related potential (ERP) and positron emission topography (PET), were used to determine the effects of odor on the nervous system. The application of these techniques to odor perception was used to clarify the relationship between odor perception and aging (Murphy *et al.*, 1994, 2000; Covington *et al.*, 1999; Geisler *et al.*, 1999; Murphy *et al.*), or to describe the differences in response to unpleasant and pleasant odors (Henkin and Levy, 2001). According to Murphy and his colleagues (Murphy *et al.*, 2000), olfactory-evoked potentials were decreased in elder subjects. Henkin and Levy (2001) reported that pleasant odors were more appreciated in the left hemisphere, while unpleasant odors were more appreciated in the right hemisphere. Martin (1998) suggested that the alterations in theta reflected shifts in attention or cognitive load during olfactory perception, and a reduction in theta indicated a reduced level of attention using multi-channel EEG responses.

Limited research has been done, through clinical case studies, on evaluating olfaction in workers occupationally exposed to chemicals (Dalton *et al.*, 1997; Chiappino *et al.*, 1998; Rydzewski *et al.*, 1998). Dalton *et al.* (1997) reported that the perceived odor and cognitive expectations about a chemical could significantly affect how individuals respond to it. A statistically significant relationship exited among olfactory impairment and cadmium concentration in blood, urine and workplace air (Chiappino *et al.*, 1998). Since neural sensitization processes could generate an endogenous amplification of responsivity to exogenous substances (Bell, 1996), EEGs have been used to evaluate sensitization to chemical exposure (Fernandez *et al.*, 1999) and to address the evidence for the criterion-related validity of the olfactory–limbic/neural sensitization model for multiple chemical sensitivity (Bell, 1996; Bell *et al.*, 1998). However, studies on EEG differences during odor stimulation for different occupational groups are rare, especially for workers in olfactory-related occupations. In the present study, mutual information analysis of multi-channel EEGs is used to examine different responses to odors among groups classified by occupations that deal with odors.

In the context of information theory, linear properties depend on second-order statistics, and nonlinear properties include higher-order statistics of the probability distribution function that describe a certain signal. If the probability distribution function of the signal is not a simple Gaussian process that has only second-order statistics, nonlinear properties appear, as well as linear activities. Multidimensional EEGs are usually considered a signal drawn from higher-order statistics, and EEGs are composed of linear and nonlinear activities (Jin *et al.*, 2003). Several linear and nonlinear studies have analyzed EEG signals in the olfactory system (Boeijinga and Lopes da Silva, 1989; Kay *et al.*, 1996; Harada *et al.*, 1998). Coherence analysis of EEGs has been widely used to measure functional relationships between different brain regions.

For the olfactory function, coherence analysis has been applied to the study of functional connectivity (Harada *et al.*, 1998). Harada *et al.* (1998) suggested that EEG coherence mapping might provide a basis for developing an objective test of the olfactory function in humans. Neural networks of the olfactory bulb, the prepiriform cortex and the entorhinal cortex have nonlinear dynamic properties; moreover, these networks showed different modes of oscillatory behavior, characteristic of a restful state and of an active sniffing state (Boeijinga and Lopes da Silva, 1989). As measured in an EEG, the activity of the olfactory bulb has been postulated to be chaotic and subject to an attractor with many 'wings' enabling different classes of learned odors to be classified (Kay *et al.*, 1996). Kay *et al.* (1996) also suggested that the attractors governing olfactory activity involved multiple sites in the olfactory/limbic system and implement the process of attention.

Coherence values only show the coupling between two neuronal populations, that is, linear connectivity. Consequently, although olfactory perceptual processing is bidirectional, as shown Kay and Freeman (1998), and includes both the linear and nonlinear properties, this kind of analysis dose not reveals the whole view of connectivity. To investigate the whole view of functional connectivity between a pair of electrodes, we used a measure of mutual information. Mutual information detects linear and nonlinear statistical dependencies between two time series (Vastano and Swinney, 1988; Yang and Gao, 1989; Xu *et al.*, 1997). It has a maximum value when the two time series are completely the same, and has a zero value if one system is completely independent of the other. This result is used as a measure of functional connectivity (Jeong *et al.*, 2001; Na *et al.*, 2002) or transmission of information between the two time series (Xu *et al.*, 1997). We estimated the transmission of information among the different cortical areas in the waking and sleep states using the cross mutual information content (CMI) of eight EEG electrodes (Xu *et al.*, 1997). In a clinical environment, Jeong *et al.* (2001) assessed the transmission of information between different cortical areas of patients suffering from Alzheimer's disease and Na *et al.* (2002) applied the same measure to schizophrenic patients. They discussed their results in terms of the cortico-cortical connection and the transmission of information between different cortical areas.

The aim of this study is to investigate the transmission of information during odor stimulation for subjects of various occupations by estimating the averaged CMI (A-CMI) between EEG electrodes.

Materials and Methods

Subjects

EEG recordings were obtained from 10 general workers (nine females and one male, with a mean age of 27.3 years), nine perfume salespersons (all females, with a mean age of 25.2 years) and 10 professional perfume researchers (five females and five males, with a mean age of 32.2 years). All subjects had a normal nasal anatomy, which was checked by a mask test; all had been in their present occupation for >5 years; they were prohibited from drinking, smoking or taking any drugs, including caffeine; and they were all right-handed. All experiments were conducted in accordance with the Declaration of Helsinki.

Stimulation

Odors such as basil oil, lavender oil, lemon oil, jasmine oil, ylang-ylang oil (KIMEX Co. Ltd) and skatole (Takasago Co. Ltd) were presented through an olfactometer while subjects reclined with eyes closed. The olfactometer, a device that scatters odor through Teflon tubes with an inner diameter of 2 mm, was placed below the nares of the subjects. The odor stimulation was achieved by mixing the pulses of the stimulants in a constantly flowing air stream with a total flow rate at 100 ml/s. We set the scattering frequency of each odor in accordance with the individual inhalation rate of each subject to avoid mismatching odor stimulation with respiration. An experimental chamber was maintained with a controlled air temperature at 24 ± 1°C and with relative humidity at 50 ± 10%. Figure 1 shows a schematic flow diagram of the presentation sequences of the odor stimuli.

Recording

As a baseline, EEGs were recorded for 90 s without odor stimulation. Six kinds of odors were then prepared and presented in random order to each subject. We recorded EEGs every 90 s during odor stimulation. The chamber was

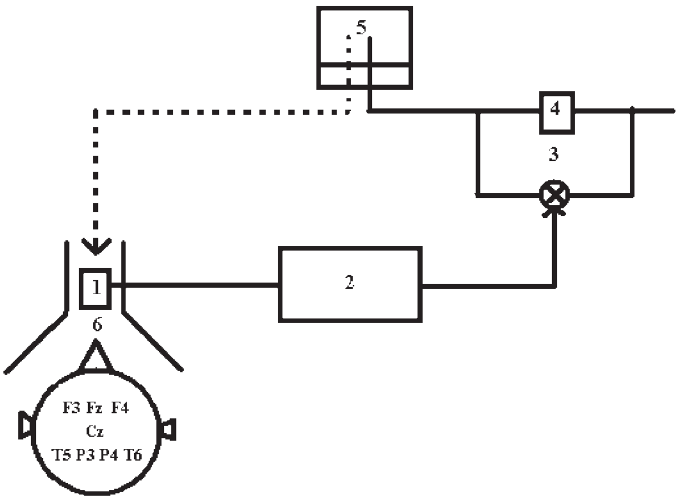

Figure 1 Schematic diagram showing the experimental paradigm. The scattering frequency of each odor is set in accordance with individual inhalation rate, which is determined using a temperature sensor (1) and a controller (2). The olfactometer presents each odor stream using a flow rate of 100 ml/s regulated by a flow regulator (4) through a sniffing funnel (6), which is a Teflon tube with an inner diameter of 2 mm. 1, temperature sensor; 2, temperature controller; 3, needle valve; 4, flow regulator (100 ml/s); 5, odor container; 6, sniffing funnel.

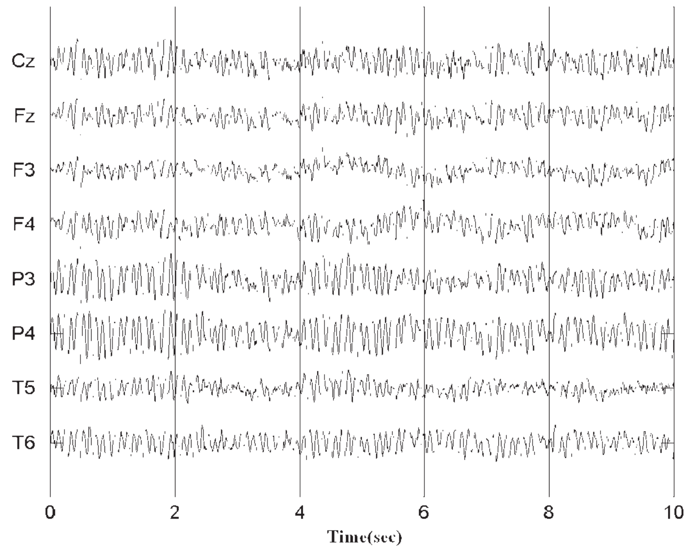

Figure 2 Typical example of EEG segments of 10 s from eight channels from a subject in rest state.

ventilated after each odor stimulus. A total of 630 s of recordings were acquired with a sampling frequency of 256 Hz; the recordings were digitized using a 12 bit analog–digital converter on an IBM PC. The EEGs were recorded from 8 scalp loci (F3/4, P3/4, T5/6, Fz and Cz) of the international 10–20 system. The EEGs from 8 channels against linked earlobes were amplified on a Biopac System with a time constant of 0.1 s. Figure 2 demonstrates a typical example of 10 s EEG segments showing eight channels from a subject in rest state. All data were digitally filtered with a band pass of 0.3–60 Hz. A questionnaire was used to obtain individual psychological preferences for the odors. After inhaling each odor, the subjects were asked to describe their subjective feelings by selecting an adjective from among 25 adjectives and assigning a rating on a seven-point scale, from –3 (insensible level) to +3 (sensible level). For every odor stimulus we used 8 s of data (2048 data points) for mutual information analysis.

Mutual information analysis

Mutual information is a measure of the amount of information gained about one system from the measurement of another. Consider a process in which messages are transmitted to an experimenter across the channel of an instrument. Let T be the whole set composed of an element of possible messages $t_1, t_2, t_3, \ldots, t_n$ and probability $P_T(t_1)$, $P_T(t_2), P_T(t_3), \ldots, P_T(t_n)$. The average amount of information gained from the measurement of T is the entropy H of the system

$$H(T) = -\sum_{t_i \in T} P_T(t_i)\log P_T(t_i)$$

where $P_T(t_i)$ is the associated probability that an isolated measurement will find the system in the ith element, and $P_T(t_i)$ is the normalized histogram of the distribution of values observed for the measurement t. We evaluate these probabilities by constructing a histogram of the variations of the measurement t. The entropy H is in units of bits if we take to logarithm with the base two. If the transmitted messages are continuous, T will be the system, and t denotes a possible message, while $P_T(t_i)$ is the probability density at t. In addition, entropy, which is a measure of uncertainty, then becomes the self-information of a system. If we consider a general coupled system (T,R) and examine the uncertainty in a measurement of R when the given T has been measured and found to be t_i, then

$$H(R|t_i) = -\sum_{r_j \in R} P_{RT}(r_j|t_i)\log P_{RT}(r_j|t_i)$$
$$= -\sum_{r_j \in R} \frac{P_{RT}(r_i, t_j)}{P_T(t_i)}\log\frac{P_{RT}(r_i, t_j)}{P_T(t_i)}$$

where $P_{RT}(r_j|t_i)$ is the probability that a measurement of r will produce r_i when the measured value of t is t_i. The uncertainty of r for a given measurement of t is obtained by averaging the above equation over t_i, and then

$$H(R|T) = -\sum_{r_i \in R, t_j \in T} P_{RT}(r_i, t_j)\log\frac{P_{RT}(r_i, t_j)}{P_T(t_j)}$$
$$= H(R, T) - H(T)$$

where

$$H(R|T) = -\sum_{r_i \in R, t_j \in T} P_{RT}(r_i, t_j)\log P_{RT}(r_i, t_j)$$

Here, we can obtain the mutual information as the amount by which the measurement of T reduces the uncertainty of R. The mutual information $I(R,T)$ is as follows:

$$I(R, T) = H(R) - H(R|T) = H(R) + H(T) - H(R, T) = I(T, R)$$

The mutual information can then be rewritten as:

$$I(R|T) = -\sum P_{RT}(r_i, t_j)\log\frac{P_{RT}(r_i, t_j)}{P_R(r_i)P_T(t_j)}$$

Mutual information has a maximum value when the two time series are completely the same; and, if one system is completely independent of the other, the mutual information is zero. We computed the time-delayed mutual information as follows (Jeong *et al.*, 2001; Na *et al.*, 2002):

$$I(R(t), T(t+\tau)) = -\sum_{r(t) \in R, t(t+\tau) \in T} P_{R(t), T(t+\tau)}(r(t), t(t+\tau)) \times \log\frac{P_{R(t), T(t+\tau)}(r(t), t(t+\tau))}{P_{R(t)}(r(t))P_{T(t+\tau)}(t(t+\tau))}$$

The time-delayed CMI, $I(R(t),T(t + \tau))$, which represents the mutual information of the EEG between different electrodes as a function of time delay, along with the A-CMI values, were used as a measure for mutual coupling or for information transmission between different cortical areas. To estimate the probability density $P_{RT}(r,t)$ from a histogram, we used 64 bins to construct the histogram from experimental data. This process provided stable estimates of probability. To investigate brain functional connectivity, we estimated the CMI of each EEG as a function of time delay for F3F4, P3P4, T5T6, F4F3, P4P3 and T6T5 pairs over time delays of 0–500 ms. The term F3F4 represents the pair of the electrodes between the F3 channel and the F4 channel, while F4F3 indicates the pair of electrodes between the F4 channel and the F3 channel. That is, F3F4 means that the transmitted channel is F3 and the received channel is F4, and vice versa for F4F3. Since

$$I(R(t),T(t + \tau)) \neq I(T(t),R(t + \tau))$$

the A-CMI of the F3F4 pair differs from that of the F4F3 pair. The detailed derivation of these equations is presented elsewhere (Shannon and Weaver, 1949; Fraser and Swinney, 1986; Cover and Thomas, 1991).

The A-CMI values for six pairs of two different cortical areas were estimated from three different occupation groups between all odor stimuli. We investigated the difference in cortico-cortical coupling within groups for different odors.

The results of the A-CMI were examined statistically using a repeated measure analysis of variance (ANOVA) with a condition factor (Condition; rest/six odor stimuli, seven levels) and with a subject factor (Electrode; six pairs of electrodes). For post-hoc analysis, a paired t-test (SPSS 6.0) was used to evaluate the statistical differences in the A-CMI of each pair of electrodes within each group that had a threshold significant level of $P < 0.05$.

Results

First, we assessed individual psychological preferences for odors. For example, the group of professional perfume researchers selected six factors from among the 25 adjectives shown in Table 1. In this group, the first factor was 'a refreshing feeling'; the second, 'a soft feeling'; the third, 'a graceful feeling'; the fourth, 'an individual feeling'; the fifth, 'a natural feeling'; and the sixth, 'a romantic feeling'. The group of professional perfume researchers then ranked six essential oils—lemon, ylang-ylang, lavender, jasmine, basil and skatole—by order of odor preference (Figure 3). We similarly obtained the order of odor preference for the other two groups of subjects.

The general workers group

The order of odor preference for general workers was as follows: lemon, ylang-ylang, jasmine, lavender, basil and skatole. An ANOVA yielded significant main effects for Condition [$F(6,419) = 2.634$, $P < 0.05$] and for Electrode [$F(5,419) = 8.078$, $P = 0.0000$]. No significant interaction for Condition × Electrode was found [$F(30,419) = 0.339$, P = NS (no significance)]. Post-hoc comparisons demonstrated several significant changes in A-CMI values. A higher A-CMI value suggests mutually stronger functional coupling between the two different time series. In the F3F4 and F4F3 pairs, increased mutual coupling was observed for the lavender and lemon stimuli, relative to a no-odor baseline. The general workers had a higher A-CMI in the P3P4 and P4P3 pairs for the lavender stimulus in comparison with the no-odor baseline. They also had a higher A-CMI value in the T6T5 pair for the lemon stimulus in comparison with the ylang-ylang stimulus. The A-CMI values had no correlation with the psychological preference. Figure 4 shows the pairs that had a significant change in the A-CMI values for all cases.

The perfume salespersons group

The order of odor preference for the perfume salespersons was as follows: jasmine, lemon, lavender, ylang-ylang, basil and skatole. An ANOVA yielded significant main effects for Condition [$F(6,377) = 5.603$, $P = 0.0000$], and for Electrode [$F(5,377) = 6.334$, $P = 0.0000$]. No significant interaction for Condition × Electrode was found [$F(30,377) = 0.714$, P = NS]. As a result of post-hoc comparisons of the F3F4 pair, the perfume salespersons group had a higher A-CMI value for the basil stimulus than it did for an odorless stimulus or to lavender. In addition, the A-CMI value for the skatole stimulus increased more than it did for the lavender stimulus. The salespersons had a higher A-CMI value in the F3F4 and F4F3 pairs in response to the skatole stimulus

Table 1 Contribution of factors in the professional perfume researchers group

	Component					
	1	2	3	4	5	6
Sporty	0.908	9.87E–02	–6.93E–03	7.23E–02	–0.193	0.105
Merry	0.895	9.75E–02	–8.84E–02	5.83E–02	4.18E–02	0.102
Bright	0.882	0.22	6.12E–03	–6.03E–02	0.179	4.86E–02
Clean	0.881	7.13E–02	9.02E–02	–0.121	0.126	4.06E–02
Comfortable	0.863	5.52E–02	0.179	8.85E–02	0.154	0.182
Active	0.862	3.92E–02	–0.231	0.108	4.92E–02	9.93E–02
Refreshing	0.831	–0.121	0.229	3.82E–02	0.179	–0.111
Light	0.744	0.243	–5.35E–03	–0.296	0.141	–0.34
Urbane	0.561	0.409	0.275	4.09E–02	–0.344	0.24
Warm	–0.171	0.822	–6.42E–02	0.155	0.273	4.90E–02
Feminine	0.251	0.797	0.152	–0.121	9.62E–02	0.149
Splendid	0.161	0.765	0.279	0.114	–0.123	0.213
Passional	6.57E–02	0.716	0.303	0.159	–0.127	–0.258
Delicate	0.145	0.619	0.254	–6.99E–02	7.65E–02	0.338
Elegant	5.02E–02	0.206	0.91	7.11E–02	5.10E–02	0.17
Graceful	0.167	0.327	0.843	6.81E–02	3.26E–02	0.225
Antique	–0.47	0.192	0.658	9.73E–02	0.25	–0.11
Individual	6.42E–02	–3.71E–02	–6.61E–03	0.813	6.38E–02	0.121
Impressive	–4.44E–03	–1.97E–02	0.183	0.771	0.145	–5.48E–04
Strong	–5.44E–02	0.205	7.33E–02	0.729	–0.102	–3.29E–02
Natural	0.407	5.98E–02	4.62E–02	0.215	0.761	–6.55E–02
Easy	0.319	0.333	0.335	0.123	0.676	5.60E–02
Exciting	0.294	0.327	4.69E–02	0.395	–0.524	1.46E–02
Stimulating	–0.328	0.363	–0.212	0.388	–0.464	–0.413
Romantic	0.114	0.273	0.248	0.126	–3.73E–02	0.776
Eigenvalue	8.23	4.4	2.36	1.95	1.43	1.01
% of Variance	33.07	17.61	9.45	7.80	5.73	4.05
Cumulative %	33.07	50.68	60.13	67.93	73.66	77.71
Factors	Refreshing	Soft	Graceful	Individual	Natural	Romantic

than they did for the odorless stimulus or the lavender. In the P3P4, P4P3, T5T6 and T6T5 pairs, this group's A-CMI value was higher for basil than for jasmine. Furthermore, in the T6T5 pair, the group's A-CMI value was significantly higher for the basil stimulus than for the lavender. The A-CMI of the salespersons was related to psychological preference; that is, they had a lower A-CMI value when stimulated by an odor for which they had a higher preference in comparison to the other odors. Figure 5 shows the pairs that had a significant change in A-CMI values for all cases.

The professional perfume researchers group

The order of odor preference for the group of professional perfume researchers was as follows: lemon, ylang-ylang, lavender, jasmine, basil and skatole. An ANOVA yielded no significant main effects for Condition [$F(6,419) = 0.017$, $P =$

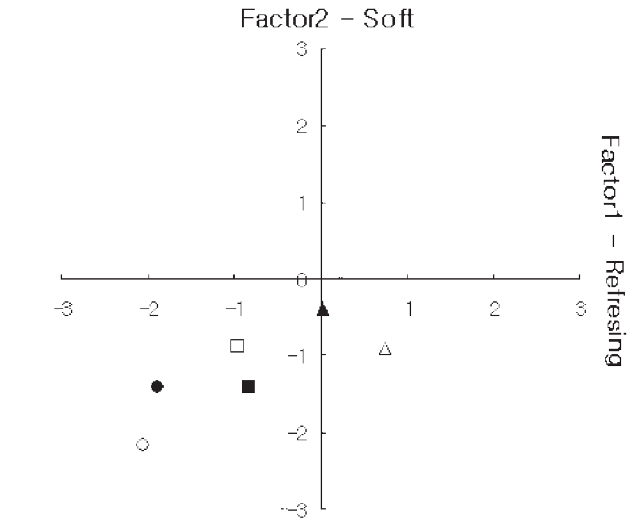

Figure 3 Results of factor analysis for the group of professional perfume researchers (filled circle, basil oil; filled triangle, jasmine oil; filled square, lavender oil; open triangle, lemon oil; open circle, skatole; open square, ylang-ylang oil). The *x*-axis indicates the first factor (a refreshing feeling) and the *y*-axis indicates the second factor (a soft feeling), for stimulation with six essential oils.

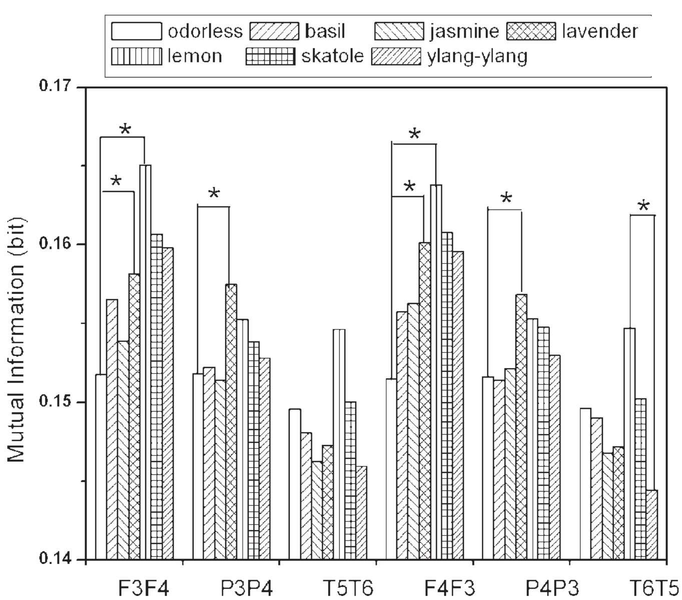

Figure 4 The pairs with significant changes in A-CMI values for all cases within the general workers group. In the F3F4 and F4F3 pairs, the A-CMI value observed during the lavender and lemon stimuli increases, relative to a no-odor baseline. The general workers have a higher A-CMI value in the P3P4 and P4P3 pairs for the lavender stimulus than for the no-odor baseline. They also have a higher A-CMI value in the T6T5 pair for the lavender stimulus than for the ylang-ylang stimulus. $^{*}P < 0.05$.

NS], for Electrode [$F(5,419) = 0.010$, P = NS], or Condition × Electrode [$F(30,419) = 0.003$, P = NS]. However, a paired *t*-test showed a lower A-CMI value in the F3F4 and F4F3 pairs for the lavender stimulus than for the basil or odorless

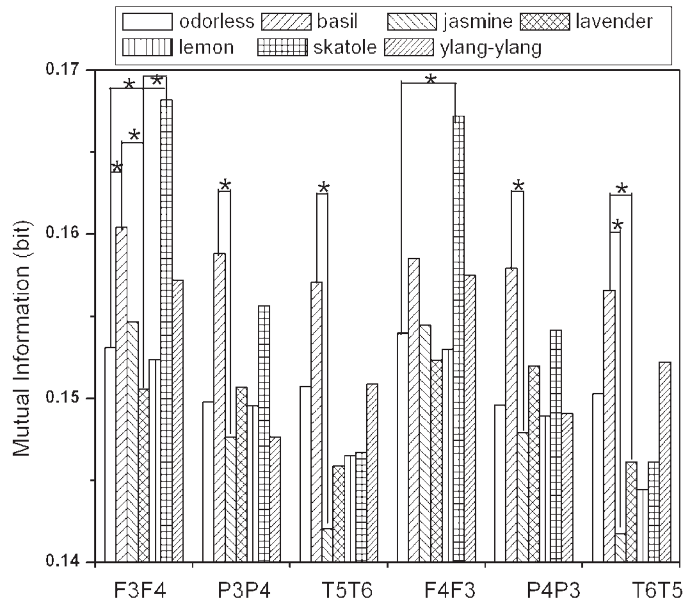

Figure 5 The pairs with the significant changes in the A-CMI values for all cases within the perfume salespersons group. The A-CMI value in the F3F4 pair is higher for the basil stimulus than for the odorless stimulus or lavender. The A-CMI value is higher for the skatole stimulus than for the lavender stimulus. The salespersons have a higher A-CMI value in the F3F4 and F4F3 pairs for the skatole stimulus than for the odorless or lavender stimuli. The A-CMI value in the P3P4, P4P3, T5T6 and T6T5 pairs is higher for basil than for jasmine. In the T6T5 pair, the A-CMI value for the basil stimulus is significantly higher than for lavender. $^{*}P < 0.05$.

stimulus. In this group, significantly different results were revealed in the mid-frontal pairs. As was the case for the perfume salespersons group, this group had a lower A-CMI value when stimulated by a relatively unpleasant odor. Figure 6 shows the pairs that had a significant change in A-CMI values for all cases. We investigated Pearson's correlation coefficient between females and males to examine whether a sex difference existed. As no correlation occurred between sex differences in the significantly different pairs of electrodes, we excluded them from our study.

Discussion

Analysis of the A-CMI from the EEGs revealed that among the professional perfume researchers changed in the A-CMI values during odor stimulation were more apparent in the frontal region of the brain. For the general workers and the perfume salespersons, however, changes in the A-CMI values were more conspicuous in the overall posterior temporal, parietal and frontal regions.

The coding of olfactory stimuli begins with the mucosa of the olfactory epithelium, and diffuses through the mucous layer to bind with chemically receptive membranes of the olfactory receptor cells. Extending from the olfactory receptor cells are nerve filaments comprising olfactory nerve fibers; these nerve filaments connect to the olfactory bulb of the brain at a relay connection, and also connect to other

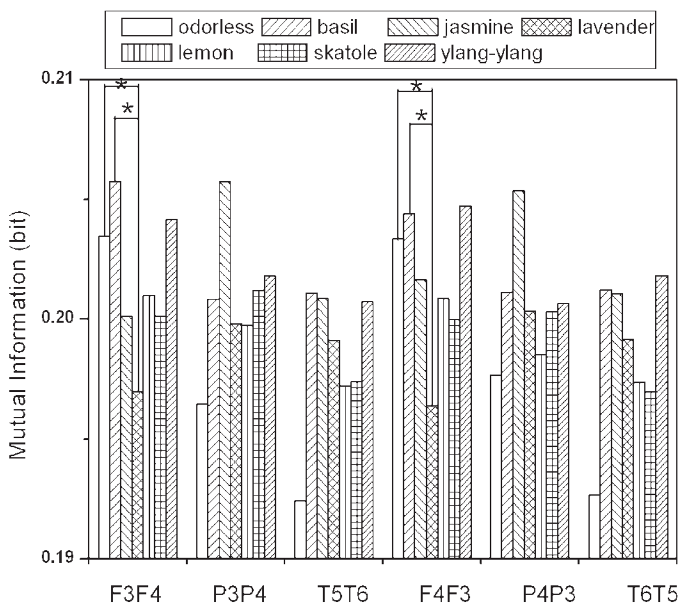

Figure 6 The pairs with the significant changes in the A-CMI value for all cases within the professional perfume researchers group. A lower A-CMI value in the F3F4 and F4F3 pairs is observed for the lavender stimulus than for the basil and odorless stimuli. In this group, the significantly different results are revealed in the frontal pairs. *$P < 0.05$.

parts of the brain by olfactory tracts (Schiffman, 1990). Anatomically, the primary olfactory cortex (POC) is located in the ventral region of the anterior temporal lobe (Gazzaniga *et al.*, 2002). The researchers sought to identify the areas of brain activity that correlated first with the act of sniffing and secondly with the act of smelling. The act of sniffing to determine whether an odorant is present or not activates the brain primarily in the pyriform cortex of the temporal lobe, and in the medial and posterior orbitofrontal gyri of the frontal lobe. The dissociation between regions activated by olfactory exploration, such as sniffing, and regions activated by olfactory content, such as smell, shows a distinction in grain organization in terms of human olfaction (Sobel *et al.*, 1998). Smelling fails to produce consistent activation in the POC—that is, continued exposure to an odorant increases the threshold or reduces the sensitivity to the odorant. In short, continued odor stimulation results in olfactory adaptation (Schiffman, 1990). The presence of the odor, however, produces a consistent increase of the orbitofrontal cortex (OFC), a region that is thought to constitute a secondary olfactory area. Thus, the role of the POC may be restricted to detecting a change in external odors, while the secondary olfactory cortex plays a critical role in identifying the smell itself (Gazzaniga *et al.*, 2002).

More precisely, the OFC regions that form the ventral surface of the frontal lobe receive olfactory information secondarily at the posterior OFC; they also receive substantial olfactory projections via the mediodorsal nucleus of the thalamus, namely the pars magnocellularis (Yarita *et al.*, 1980; Russchen *et al.*, 1987; Ray and Price, 1993; Carmichael and Price, 1996). Although the functional role of the OFC is difficult to define precisely, it is considered part of the neural basis of emotions or emotional decision making; it is also classified as the secondary olfactory area. A comparative or evolutionary perspective suggests that the prefrontal cortex arose from a very old system, called the olfactory system (Gazzaniga *et al.*, 2002). In humans, lesions to the OFC impair olfactory discrimination and identification (Jones-Gotman and Zatorre, 1988; Zatorre and Jones-Gotman, 1991). In particular, the right central OFC appears to play a critical role in recognition memory, whereas the left lateral OFC region seems to play a more central role in hedonic judgements (Zald and Pardo, 2000).

On the other hand, the posterior brain processes the physical features of stimuli, while the frontal cortex performs higher-order operations, such as evaluating the task-relevance of a stimulus (Potts and Tucker, 2001). According to the measurements of Kobal and Kettermann's functional magnetic resonance imaging (fMRI) (Kobal and Kettermann, 2000), significant activation occurred in the temporal lobe, the lateral frontal region and the medial frontal regions bilaterally for general subjects stimulated with a vanillin odor. Zald and Pardo (2000) reported that increases in regional cerebral blood flow emerge bilaterally near the inferior junction of the frontal and temporal lobes where the POC is located within the pyriform region.

Taken together, these previous studies support our results that during odor stimulation changes in the A-CMI appear at the overall posterior temporal, parietal and frontal regions. For the group of professional perfume researchers, the dominant change in the frontal region may reflect the effects of functional coupling in the OFC when being stimulated by an odor. That is, this result indicates that the brains of professional perfume researchers respond to an odor mainly in the frontal region, reflecting the function of the OFC due to the occupational requirement of these subjects to discriminate or identify odors. Although relatively more exposed to odors in their occupation, the perfume salespersons responses to odor stimulation were similar to those of the general workers. However, the A-CMI value is in inverse proportion to psychological preference among the professional perfume researchers and the perfume salespersons, though this is not the case for the general workers. To evaluate psychological profiles at the baseline of women with and without chemical intolerance, Bell *et al.* (1998) used quantitative EEG profiles; the interrelationship between physiological and psychological factors in the expression of symptoms has also been addressed (Clauw, 2001). Thus, our results suggest that functional coupling for people who are occupationally exposed to odors may be related to psychological preference, though changes in A-CMI values appear in different regions of the brain depending on occupational specialty.

Lorig (2000) pointed out a shortcoming of EEG analysis for investigating the olfactory system. Analysis of an EEG can have many problems such as how to compute coherence or which windowing technique to use when determining the power spectrum. Furthermore, while all non-artifactual EEG measurements describe a subject's different brain activities when stimulated by a different odor, the measurements unfortunately fail to tell investigators what the brain is doing. An EEG provides a continuous recording of brain activity, and an ERP provides a precise temporal record of underlying neural activity (Gazzaniga *et al.*, 2002). Thus, EEG recordings are used to detect abnormalities in brain function, and the evoked responses are considered to be a signal that reflects neural activity specifically related to cognitive events (Gazzaniga *et al.*, 2002). It is reasonable, however, to choose a tool that provides continuous brain activity for a certain period when researching the transmission of information during olfactory function. Thus, an EEG is a more suitable method than an ERP. Besides, although imaging techniques such as PET and fMRI detect changes in the brain's metabolism or blood flow while a subject is engaged in a cognitive function with high spatial resolution (Gazzaniga *et al.*, 2002), they are restricted within a narrow time resolution. Nonetheless, we can study the transmission of information or cortico-cortical interactions between two brain regions by maintaining the advantages of an EEG. Although mutual information is an indicator of functional cortico-cortical connections in the brain, including linear and nonlinear properties, the A-CMI does not reveal the actual mechanism or pathways. By using the A-CMI, however, we can quantify the transmission of information at one site from the time series at another site (Jeong *et al.*, 2001). Consequently, in spite of this shortcoming in EEG analysis, we can obtain the functional connectivity to an odor for subjects classified by occupation. To gain a better understanding of differences in the olfactory function for subjects classified by occupation, we need to extend our analysis of mutual information to an EEG experiment with a larger number of sex- and age-matched subjects, and we need to use various experimental protocols.

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