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Slow Breathing and Emotions Associated with Odor-Induced Autobiographical Memories

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Abstract

An important feature of olfactory perception is its dependence on respiratory activity. By inspiration, olfactory information ascends directly to olfactory-related limbic structures. Therefore, every breath with odor molecules activates these limbic areas associated with emotional experience and memory retrieval. We tested whether odors associated with autobiographical memories can trigger pleasant emotional experiences and whether respiration changes during stimulation with these odors. During presentation of odors related to autobiographical memories and control odors, we measured minute ventilation, tidal volume, respiratory frequency, O_2 consumption, and end tidal CO_2 concentration. Findings showed that autobiographical memory retrieval was associated with increasing tidal volume and decreasing respiratory frequency more than during presentation of control odors. Subjective feelings such as emotional arousal during retrieval of the memory, arousal level of the memory itself, or pleasantness and familiarity toward the odor evoked by autobiographical memory were more specific emotional responses compared with those related to control odors. In addition, high trait anxiety subjects responded with a stronger feeling of being taken back in time and had high arousal levels with tidal volume increases. We discussed assumptions regarding how deep and slow breathing is related to pleasantness and comfortableness of an autobiographical memory.

Key words: autobiographical memories, emotions, limbic system, respiration

Introduction

It is well known that some odors elicit special emotion or memory retrieval. It has been reported that a feeling of "going back in time" to the occurrence of an event is experienced more strongly for odor-cued memories than memories evoked by verbal and visual cues (Herz and Cupchik 1992; Herz 2004). Memories induced by odors enable individuals to mentally travel back into their personal past. These are episodic or autobiographical memories. Autobiographical odor memory studied in the field of psychology has focused on the comparison between emotional level evoked by odor and that induced by other sensory stimuli (Rubin et al. 1984; Chu and Downes 2002; Willander and Larsson 2006). These studies have confirmed that odor-evoked memories may be experienced more emotionally than memories evoked by other sensory stimuli. Autobiographical odor memory elicits strong emotions accompanied by feelings of reality for the specific memory possibly because olfaction involves a unique sensory process that differs substantially from other sensory modalities. In olfactory perception, information bypasses the thalamus to ascend directly to olfactory-related limbic structures, including the piriform cortex (Pir), entorhinal cortex (ENT), amygdala (AMG), hippocampus (HI), and orbitofrontal cortex. Direct input to these areas overlaps with areas related to emotion and memory.

The involvement of these brain areas in human olfaction and emotion has been confirmed by a number of neuroimaging studies (Zatorre et al. 1992; Sobel et al. 1998; Rolls et al. 2003; Masaoka et al. 2005). Regarding brain areas related to autobiographical odor memory, Herz et al. (2004) showed that AMG and HI activations were specific compared with areas evoked by other sensory cues.

Although brain areas related to emotions and memories triggered by odor cues have been revealed in brain imaging studies, an important feature of olfactory perception that has

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been relatively neglected is its dependence on respiratory activity. Emotional change and memory flashback may be elicited by just one breath, with odor molecules ascending to the olfactory epithelium and across a mucous membrane to bind with olfactory receptors. Upon inspiration, olfactory information ascends directly to olfactory-related limbic structures. Therefore, every breath activates these limbic areas associated with emotional experience and memory retrieval. In addition to breathing being a spontaneous activity regulated in the brainstem for metabolic and homeostatic purposes, respiration has an important role in olfactory perception and emotions (Laing 1983; Bensafi et al. 2003; Johnson et al. 2003).

It has been reported that odor stimuli change respiratory patterns. For example, pleasant odors increase tidal volume (V_T) and decrease respiratory frequency (f_R), resulting in a deep and slow breathing pattern. On the other hand, unpleasant odors decrease V_T and increase f_R, indicated by a rapid and shallow breathing pattern (Masaoka et al. 2005). These pattern changes were not caused by metabolic change or voluntary manipulation but were instead related to the activation of the limbic and paralimbic areas, which are associated with "emotional breathing" (Homma and Masaoka 2008). Accordingly, the limbic system is the center for expression of respiration, olfaction, emotions, and memories (Masaoka et al. 2005; Bensafi et al. 2007).

Our interest was to know if odors associated with personal memories can trigger pleasant emotional experiences and whether respiration that may reflect inner emotional state changes during stimulation with these odors. Also of interest was how respiratory patterns differ for other odors generally categorized as "pleasant" that do not evoke autobiographical memory retrieval.

Materials and methods

A total of 23 subjects (8 males, 15 females) were chosen from 264 subjects (aged 20–59 years) on the basis of a pretest interview. Three months prior to the procedure, we asked subjects to identify the name of a perfume that elicited a specific pleasant and personal memory. All 264 subjects were asked to briefly describe their memory and rate how emotional they felt about it. The pretest interview included the following:

1. Have you experienced a certain odor that elicits a specific memory associated with a person, place, or event?
2. Identify the name of the perfume that triggers your specific memory?
3. Write a brief description of the memory.
4. Rate the pleasantness felt when recalling the memory from the odor and the memory context (1 = very unpleasant; 5 = very pleasant).
5. Rate the vividness of the memory context (1 = not at all strong; 5 = extremely strong).
6. How strong was the feeling of being taken back in time to the occurrence of the event? (1 = not at all strong; 5 = extremely strong)
7. How emotionally intense was your memory related to the odor? (1 = not at all strong; 5 = extremely strong)

The 23 subjects examined in this study were able to identify the name of the perfume. We confirmed that the perfumes identified by subjects were not causing unpleasant feelings related to memories evoked by smelling them. All subjects were tested for sense of smell by the T & T olfactometer. All had a normal sense of smell. Subjects were free from allergies and had normal respiratory function.

All subjects provided written informed consent, and the study was approved by the Ethics Committee of the Showa University School of Medicine.

Odor stimuli

A perfume stimulus (perfume) reported from the pretest interview by each subject was prepared for olfactory presentation. These items were White Musk from the Body Shop, L'air Du Temps from Nina Ricci, Paris from Yves Saint Laurent, Voile de Jasmin from Bvlgari, Blue Jeans from Versace, Ck1 from Calvin Klein (2 subjects identified this odor), Light Blue from Dolce and Gabbana, Tactics from Shiseido, Samourai from Alain Delon, Rush 2 from Gucci, Bvlgari Black from Bvlgari, L'eau D'Issey Pour Homme from Issey Miyake, Diorella from Christian Dior, Bvlgari Pour Homme from Bvlgari (2 subjects identified this odor), L'eau D'Issey from Issey Miyake, Envy from Gucci, Eternity from Calvin Klein, O Oui! from Lancome, Sui Dreams from Anna Sui, Ptisenbon from Givenchy, and Portugal from 4711.

Two control odors were used: β-phenyl ethyl alcohol (PEA), which we used as a pleasant odor (the smell of roses) in a previous study (Masaoka et al. 2005), and chamomile, which was examined in pretesting in 150 subjects. We found that chamomile has the character of a normal odor that was not able to induce emotional change and memory retrieval.

The 3 kinds of odorant-dipped litmus strips were prepared 30 min before the experiment and left exposed to the air until the smell of alcohol disappeared. For perfume stimuli, 50 μL were attached to the tip of the litmus strip. Ten microliters of PEA diluted 5% with ethanol and Roman chamomile oil diluted 30% with ethanol were applied to the other litmus strips.

After the experiment, we asked 10 questions (subjective scale for odors) for each odor to confirm that the perfumes identified by subjects in preinterviews actually induced memory retrieval and that the 2 control odors did not induce any memory associated with a person, place, or event. We also confirmed emotional scales for each odor.

Measurement of respiration and olfactory stimulation

Because respiratory response is greatly influenced by individual trait anxiety (Masaoka and Homma 1997), we tested the

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anxiety level of all subjects using Spielberger's State and Trait Anxiety Inventory (Spielberger 1983) as subject background data. Trait anxiety level was divided into scores indicating the existence of trait anxiety (trait anxiety present) and scores indicating the nonexistence of anxiety (trait anxiety absent).

Subjects were informed that their respiratory response would be measured during presentation of 3 randomly presented odor stimuli. They were requested to breathe normally without attending to their breathing and avoid sniffing behaviors.

Subjects sat on a chair wearing a facemask with a transducer connected to a respiratory monitor (CPX, Arco System) for measurement of respiratory pattern and metabolism. The monitor calculated breath-by-breath minute ventilation (V_E), V_T, f_R, O_2 consumption (VO_2), and end tidal CO_2 concentration ($ETCO_2$). All data were stored on a laptop computer.

Each odor was presented in front of the inspiratory side of a one-way valve connected to the transducer. When the subject inspired, the inspiration side of the valve opened until the onset of expiration, when the expiratory valve opened. Odorants were inspired through the transducer, which measured respiratory data. Each odor was presented for 30 s with a 30-s air interval before the next presentation to minimize adaptation (Ekman et al. 1967). During the 30-s air interval, we confirmed that V_E and $ETCO_2$ returned to baseline level on the PC screen-connected CPX. The 3 odors of perfume, PEA, and chamomile were presented in randomized order, and each odor was tested 10 times.

Subjective scale for odors

After the experiment, we asked the following questions about each odor presented with the odorant-dipped litmus strip. Items describing questions from Parts 1 to 3 are shown in Figures 2, 3, and 4.

Does this odor bring back memories from your personal past?

If yes, please answer the following questions. If no, please go to the questions in Part 3.

Part 1: Subjective experience of emotion during memory retrieval.

1. How do you rate your emotion during retrieval of the memory related to the odor? (1 = very unpleasant; 5 = very pleasant), "Emotional change during memory retrieval" in the figures.
2. How do you rate your emotional arousal during retrieval of the memory? (1 = very calm; 5 = very aroused), "Emotional arousal during memory retrieval" in the figures.
3. How strong was the feeling of being taken back in time to the occurrence of the event during retrieval of the memory? (1 = not at all strong; 5 = extremely strong), "Strength of feeling back in time during memory retrieval" in the figures.

Part 2: Subjective scale for context of the memory.

1. How comfortable was the context of the memory? (1 = very comfortable; 5 = not at all comfortable), "Comfortableness of the memory context" in the figures.
2. How vivid was the memory? (1 = very ambiguous; 5 = very vivid), "Vividness of the memory context" in the figures.
3. How pleasant was the memory? (1 = very unpleasant; 5 = very pleasant), "Pleasantness of the memory" in the figures.
4. How aroused were you during retrieval of the memory? (1 = very calm; 5 = very aroused), "Arousal level of the memory" in the figures.

Part 3: Subjective reaction to the odor.

1. How pleasant was the odor to you? (1 = very unpleasant; 5 = very pleasant), "Feelings of pleasantness toward the odor" in the figures.
2. How intense was the odor? (1 = very weak; 5 = very strong), "Subjective intensity of the odor" in the figures.
3. How familiar was the odor? (1 = not at all familiar; 5 = very familiar), "Familiarity of the odor" in the figures.

Data analysis

All statistical analyses were performed with a commercially available statistical package (SPSS, Ver. 11.0; SPSS). Comparison of V_E, f_R, V_T, T_I, T_E, VO_2, and $ETCO_2$ between stimuli (rest, perfume, PEA, and chamomile) were analyzed by a one-way analysis of variance (ANOVA). The Greenhouse–Geisser adjustment of the degrees of freedom was applied to the ANOVA analysis to correct for violation of the assumption of sphericity. Post hoc testing was performed with the Bonferroni test. Comparison of the subjective scale for emotions and memories between the 3 stimuli were analyzed by the Kruskal–Wallis test.

The relation between subjective scales and respiratory parameters were analyzed by correlation coefficients for the linear regression lines. P values were calculated for each line to determine any significant correlations. Data are shown as means and standard deviations (Figure 1), and the means of each emotional scale are represented in a bar graph for each trial. The scattered plots in Figure 3 indicate individual raw data of subjective scale and anxiety scores. The increase of V_T in Figure 4 indicates the mean value of the increase of V_T (V_T during perfume stimuli and rest) calculated for each subject and individual raw scores of emotional scales and anxiety scores.

Results

The perfume identified by each subject successfully induced an autobiographical memory. Seventeen subjects reported

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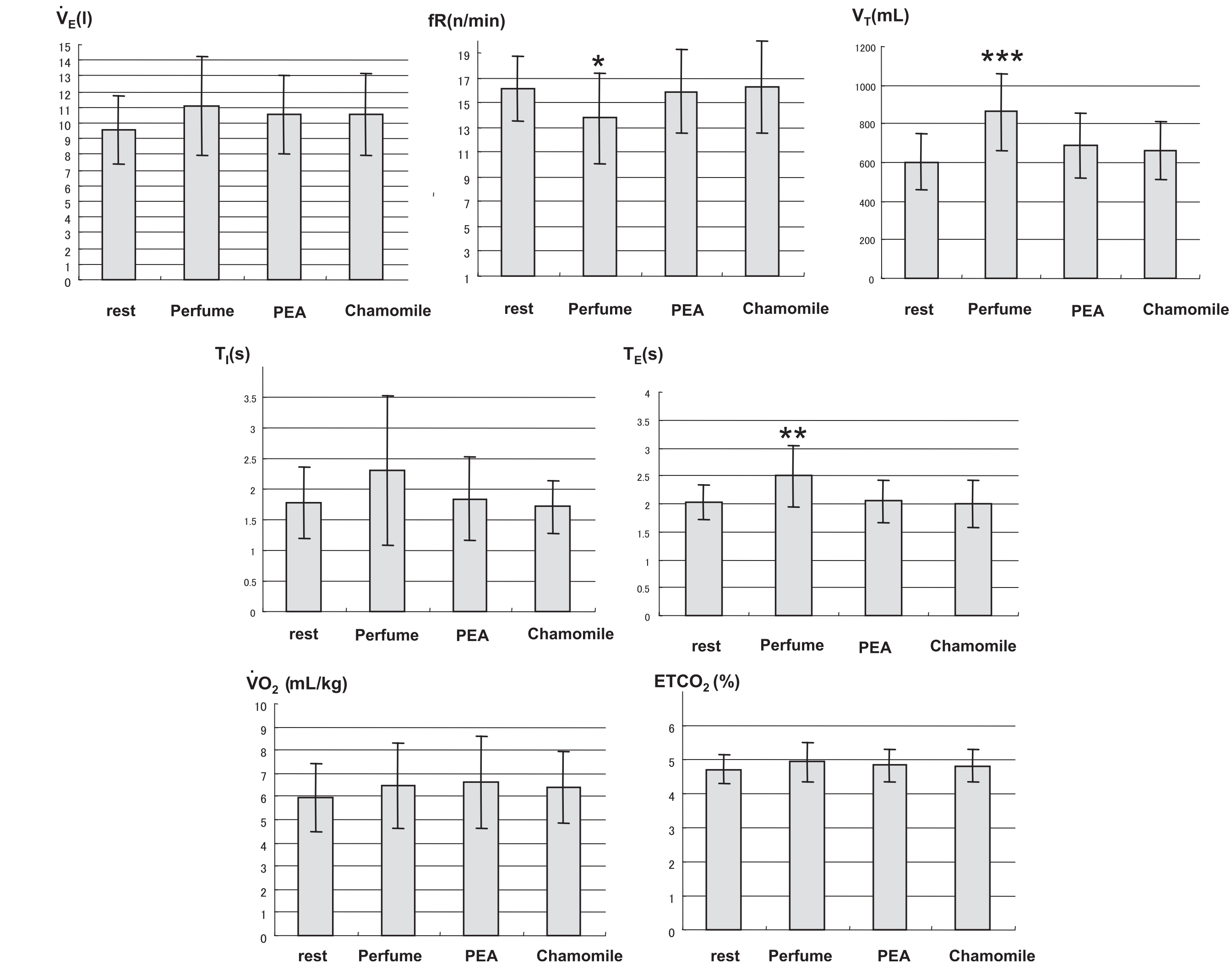

Figure 1 Comparison of respiratory parameters between rest, perfume, PEA, and chamomile. VE, V_T, f_R, O_2 consumption (VO_2), $ETCO_2$. $*P < 0.05$, $**P < 0.01$, $***P < 0.001$.

that they actually felt taken back in time to the memory of the past. For 3 subjects, the perfume did not evoke an autobiographic memory, and another 3 subjects recognized the odor of perfume associated with a past experience when they completed the subjective scale for odors after the experiment. Six subjects were excluded from the data. Therefore, data for 17 subjects were used in the analysis for rest and all odors. Two examples of memories provided by subjects are as follows:

Example 1: Scene in a beauty salon where I was sitting for my haircut. Besides me, my mother was there. Her hair had already been set.

Example 2: Seeing my favorite perfumes setting on the shelf, feeling very comfortable choosing one of the perfumes. When wearing that perfume, I enjoyed being with my friends and boyfriend, whom I was seeing often.

Respiratory parameters

Figure 1 shows a comparison of respiratory parameters between rest, perfume, PEA, and chamomile. There was a significant difference between trials (F = 4.4, P < 0.01). f_R significantly decreased during perfume stimulation compared with rest, PEA, and chamomile (P < 0.05). There was a significant change in V_T between trials (F = 6.47, P < 0.001), and perfume increased V_T more than rest and the other stimuli (P < 0.05), indicating that perfume stimulation was associated with a slow and deep breathing pattern. Perfume stimulation slightly increased V_E, but this increase did not reach significance (F = 0.83, P = 0.49). Thus, V_E remained significantly unchanged for all the odor stimuli. A decrease in f_R and increase in V_T was not caused by metabolic change, as confirmed by unchanged VO_2 (F = 0.33,

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$P = 0.8$). This means that changes were due to an association with olfactory stimuli or olfactory-induced emotional change. Also, despite respiratory change observed during perfume stimulation, $ETCO_2$ was maintained at a resting level ($F = 0.51$, $P = 0.68$). Longer T_I and T_E caused slower respiratory time resulting in an f_R decrease. Observing T_I and T_E in our results, the decrease in f_R was mainly caused by an increase in T_E ($F = 4.53$, $P < 0.01$). The increase of T_I was statistically dispersed. Thus, this increase did not reach significance ($F = 1.8$, $P = 0.19$).

Subjective scales

Scale data were averaged from 17 subjects and compiled in stimuli bar graphs. Subjective scales (comprising questions 1–10) were compared between the 3 odors (Figure 2). Among these scales, emotional arousal during memory retrieval ($F = 7.1$, $P < 0.01$), arousal level of the memory ($F = 7.8$, $P < 0.01$), pleasantness toward the odor ($F = 5.6$, $P < 0.001$), and familiarity of the odor ($F = 4.8$, $P < 0.05$) were significantly different. These scores were significantly higher than those for PEA ($P < 0.01$) and chamomile ($P < 0.01$). There was no significant difference between the 3 odors for emotional change during memory retrieval, $F = 1.5$, $P = 2.3$; strength of feeling back in time during memory retrieval, $F = 0.8$, $P = 0.45$; comfortableness of the memory context, $F = 2.4$, $P = 0.1$; vividness of the memory context, $F = 0.7$, $P = 0.47$; pleasantness of the memory, $F = 2.1$, $P = 0.13$; and subjective intensity of the odor, $F = 2.8$, $P = 0.06$.

For perfume stimuli, we investigated whether there was any significant interrelationship between emotional scores. The right side of Figure 2 shows that emotional arousal during memory retrieval correlated with emotional change during memory retrieval ($P < 0.01$), with strength of feeling back in time during memory retrieval ($P < 0.05$) and with pleasantness of the memory ($P < 0.01$). Pleasantness toward the odor correlated with comfortableness of the memory context ($P < 0.01$) and with pleasantness of the memory ($P < 0.01$). Familiarity of the odor correlated with vividness of the memory context ($P < 0.05$).

Relation between subjective scale, anxiety scores, and V_T

The mean score for trait anxiety was 45.2 ± 5.5. Trait anxiety scores were divided into trait anxiety present scores (mean 19.6 ± 3.6) and trait anxiety absent scores (mean 25.7 ± 3.9).

We examined the relation between subjective scales and trait anxiety present scores (anxiety scores in figures and following text) to see if emotional scores differed in individuals depending on anxiety level. We found significant correlations between emotional arousal during memory retrieval and anxiety scores and between arousal level of the memory and anxiety scores (both $r = 0.46$, $P < 0.05$; Figure 3A,B). Subjects with high anxiety tended to have an increased arousal level during retrieval of the memory and may have experienced the same arousal level as when the event actually happened.

Strength of feeling back in time during memory retrieval appeared to be correlated with anxiety scores but did not reach significance ($r = 0.37$; Figure 3C). Perfume altered respiratory patterns, in particular increasing V_T more than other stimuli. This increase in V_T was correlated with anxiety scores ($r = 0.48$, $P < 0.059$; Figure 3D). Given that anxiety scores were correlated with emotional arousal and arousal level of the memory, we tested for any relation between an increase in V_T and these subjective ratings. Subjects with high emotional arousal during memory retrieval and arousal level of the memory tended to have an increase in

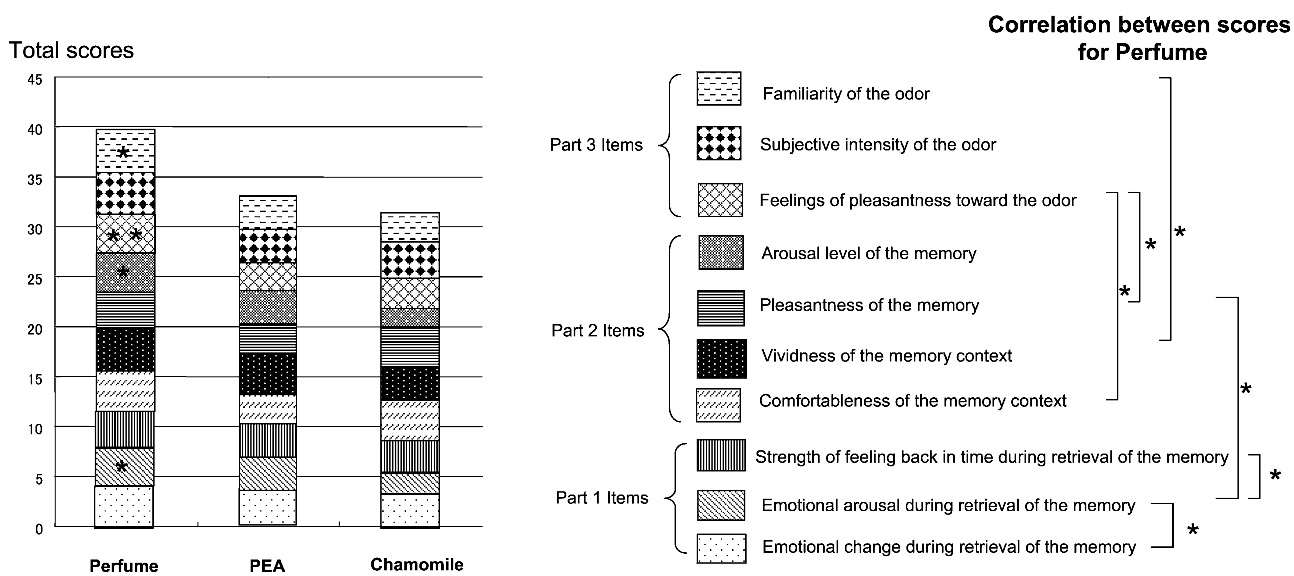

Figure 2 Left: Scale data were averaged from 17 subjects and compiled in stimuli bar graphs. Subjective scales (comprising questions 1–10) were compared between the 3 odors. *$P < 0.05$, **$P < 0.01$. Right: Correlation between scores for perfume. *$P < 0.05$.

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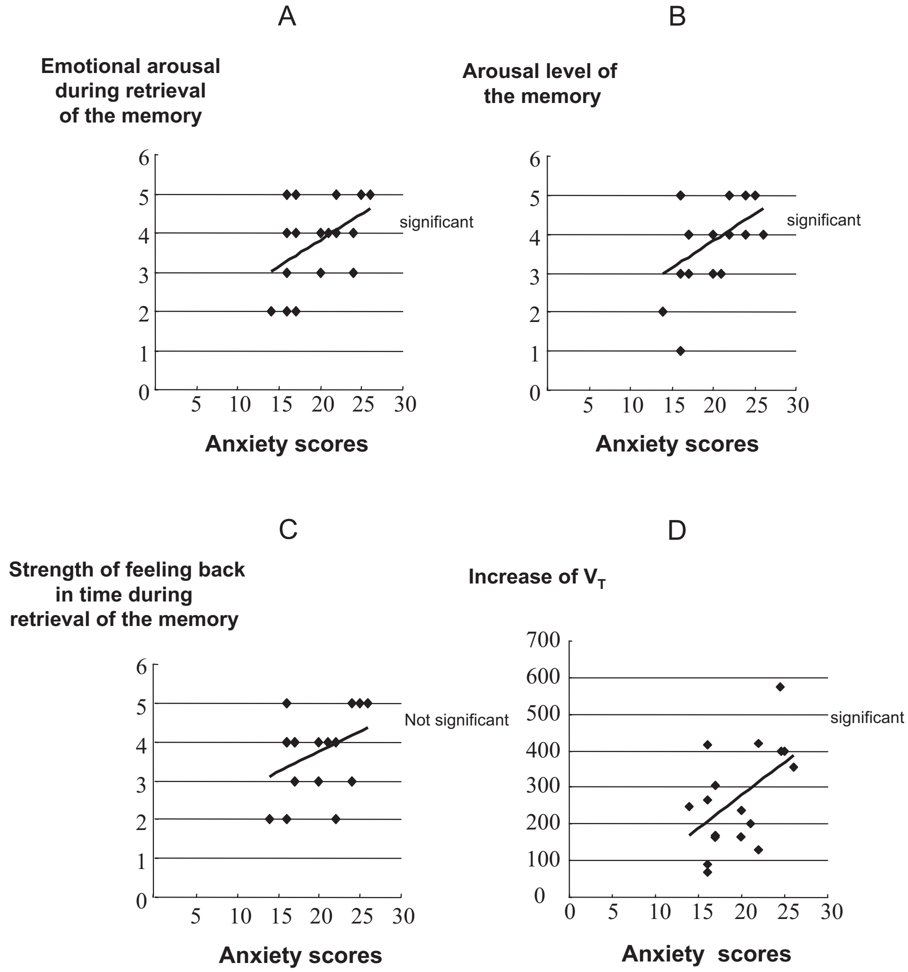

Figure 3 Correlation between subjective scales and anxiety scores (trait anxiety present scores) using data from 17 subjects. **B**, **C**, and **D** have only 15 data points because some subjects had the same anxiety score and emotional score or similar V_T responses. In B, 2 subjects with a score of 17 and 2 subjects with a score of 16 for anxiety had a score of 4 and 5 for arousal level of the memory, respectively. In C, 2 subjects with a score of 17 and 2 subjects with a score of 16 for anxiety had a score of 4 for feeling back in time during the memory. In D, 2 subjects with an anxiety score of 17 had 154.5 and 154.6 mL of V_T, respectively.

V_T (Figure 4A,B), but the increase did not reach significance ($r = 0.3$, $P > 0.05$ and $r = 0.28$, $P > 0.05$, respectively). On the other hand, subjects reporting a strong feeling of being back in time during memory retrieval had more of an increase in V_T ($r = 0.48$, $P < 0.05$; Figure 4C).

Subjects with a high increase in V_T during delivery of perfume stimuli seemed to have a decrease in f_R. However, a decrease in RR was not negatively correlated with the anxiety score. A decrease in f_R was significantly negatively correlated with emotional arousal ($r = 0.33$, $P < 0.05$) and with arousal level of the memory ($r = 0.51$, $P < 0.05$).

Discussion

The present study provides evidence of the emotional potency of odor-evoked autobiographical memory, shown by deep and slow breathing. This phenomenon was not caused by metabolic demand, confirmed by unchanged O_2 consumption, but was instead caused by inputs from higher brain centers. In addition, autobiographical memory retrieval was associated with deep and slow breathing more than during presentation of control odors. Subjective feelings such as emotional arousal during memory retrieval, arousal level of the memory, or pleasantness and familiarity toward the odor evoked by autobiographical memory were more specific emotional responses compared with those related to control odors. These subjective emotional experiences related to higher structures in the brain override the spontaneous respiration regulated by the brainstem, expressed by an increase in V_T and slower f_R.

In a previous study on the relation between respiration and olfaction (Masaoka et al. 2005), PEA used as a pleasant odor increased V_T and decreased f_R. In this study, PEA increased V_T compared with resting level. However, 4 group comparisons did not reach significance (comparison between rest and PEA by the Wilcoxon signed rank test, $P < 0.001$)

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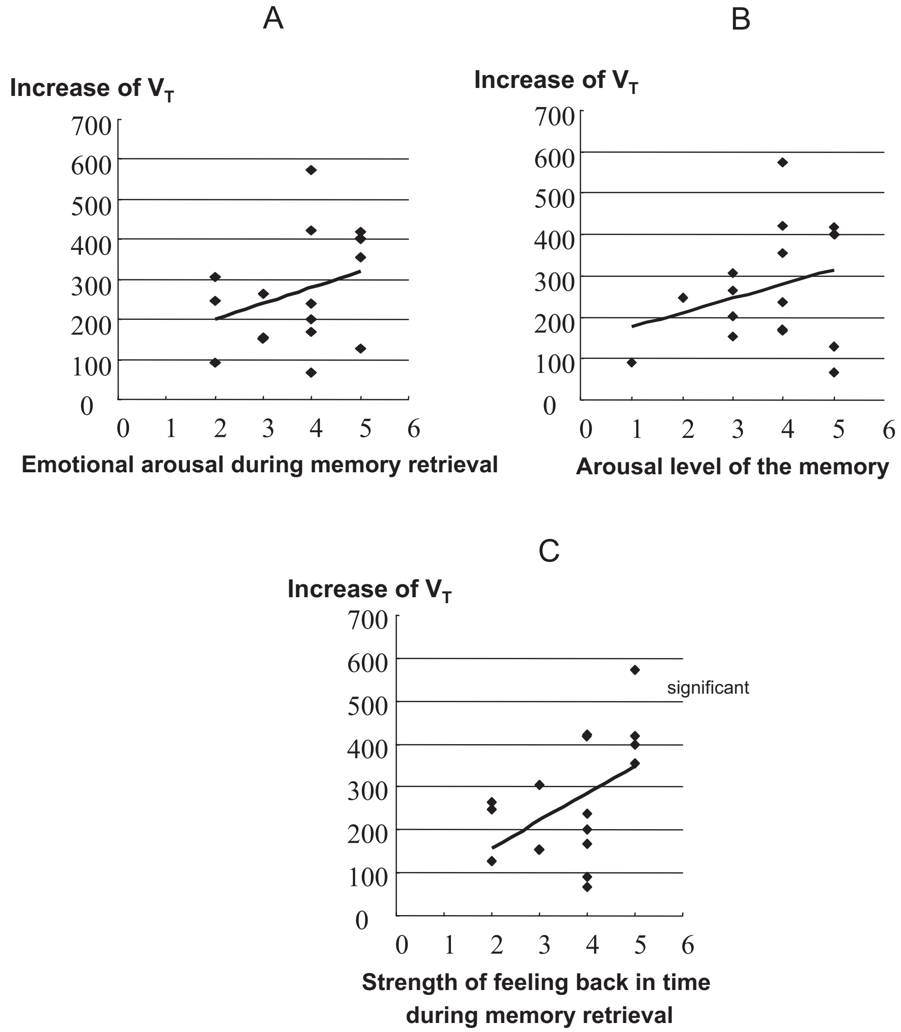

Figure 4 Correlation between an increase in V_T and subjective ratings using data from 17 subjects. **A**, **B**, and **C** have only 15 data points because some subjects indicated the same emotional score with similar V_T responses. In A, 2 subjects with a score of 3 for emotional arousal during memory retrieval had 154.5 and 154.6 mL of V_T, respectively. Two subjects with a score of 5 for emotional arousal during memory retrieval had 417 and 416.9 mL of V_T, respectively. In B, 2 subjects with a score of 5 and 2 subjects with a score of 4 for arousal level of the memory had 417 or 416.9 mL of V_T and 154.5 or 154.6 mL of V_T, respectively. In C, 2 subjects with a score of 4 and 2 subjects with a score of 3 for strength of feeling back in time during memory retrieval had 417 or 416.9 mL of V_T and 154.5 or 154.6 mL of V_T, respectively. Data points for subjects with a score of 5 for strength of feeling back in time during memory retrieval with 416.9 mL V_T were superimposed on those for 417 mL of V_T.

because the increases in V_T during stimulation with autobiographical odors were more specific with significant subjective feelings compared with the 2 controls.

Three assumptions are discussed regarding how deep and slow breathing is related to pleasantness and comfortableness of an autobiographical memory. One assumption is that deep breathing is caused by pleasant feelings at the moment, or this response is a reexpression of pleasantness felt in the past, thus involving 2 aspects. The second assumption, from a physiological view, is that deep breathing may contribute to increased feelings of pleasantness and comfortableness. The third assumption is that an increase in V_T elicited by an autobiographical pleasant memory is dependent on the degree of individual subjective feelings and trait anxiety.

Deep and slow breathing associated with autobiographical pleasant memory

To discuss the first assumption, deep and slow breathing must be defined by comparing breathing changes associated with positive and negative emotions. It has been reported in respiratory psychophysiology that various emotions alter breathing patterns; in particular, the studies focused on negative emotions such as fear and anxiety and respiratory changes (Boiten et al. 1994; Masaoka and Homma 2001; Hegoburu et al. 2011). Fear and anxiety increase f_R without a change in metabolic demand, indicating that the changes are due to higher brain activations. The limbic system dominantly affects respiratory output compared with brainstem respiratory regulation of homeostasis. The center of the

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limbic system, the AMG, plays an important role in emotions (Davis 1992). The relation between the AMG and respiration has been examined in a number of studies. Electrical stimulation of the AMG increased f_R in animals (Harper et al. 1984) and humans (Masaoka and Homma 2004a). Lesions in the AMG decreased anxiety as well as f_R during anticipation of anxiety. Anticipatory anxiety increased f_R coactivated with the AMG in a brain imaging study (Masaoka and Homma 2000). Negative emotions coactivated with AMG suggest that increased f_R is a part of the response related to defense mechanisms, that is, to increased alertness and arousal level (Davis 1992).

On the contrary, pleasant feelings decrease f_R and increase V_T (Masaoka et al. 2005). Slow and deep breathing has been observed in individuals in a relaxed state, and a decrease in anxiety has been associated with a decrease in f_R (Boiten et al. 1994). It has also been reported that even conscious control of slow breathing decreases anxiety (Masaoka and Homma 2004b). Feelings of pleasantness and comfortableness are associated with slow and deep breathing, and breathing patterns can fluctuate between the extremes of unpleasant and pleasant emotions.

Olfactory responses fluctuate as well. Pleasant odors have been shown to decrease f_R and increase V_T, even without consciousness. In addition, detailed analysis has revealed that a decrease in f_R is caused by an increase in T_E, which is normally shortened in a negative state, allowing enhancement of T_I initiation (Masaoka and Homma 1997). Slow and deep breathing observed during odor-evoked autobiographical memory in this study might be an index for indicating that a subject feels pleasantness and is in a state of relaxation.

Slow and deep breathing being associated with autobiographical odors more than with control odors may involve 2 factors. First, the memory evoked by the odor has a pleasant context, and subjects might have been expressing the same respiratory response toward the odor as in the past. The olfactory process is closely connected to respiratory activities (Masaoka et al. 2005; Bensafi et al. 2007), and olfactory information ascends directly to the AMG, the center of emotions, and the ENT, which is the gateway to the HI (Schoenbaum et al. 1999). This direct link may have an advantage for the odor-related conditioning process of emotion (LeDoux 2000). The context of the memory might be more pleasant, vivid, and clear during slow and deep breathing, with an increased arousal level automatically evoked by the odor.

In addition to this, slow breathing causes increased activation of bronchopulmonary vagal afferents and produces heart rate variability, which reflects increased parasympathetic tone (Berntson et al. 1993). These physiological responses may contribute to feeling emotions more strongly (Damasio 1996). Reproducing slow and deep breathing experienced in the past may contribute additionally to feeling "pleasantness" and "comfortableness."

Second, once we experience pleasantness through an odor-induced autobiographical memory, an expectation of the next inspiration might occur. Although the slow and deep breathing pattern in this study seemed to occur unconsciously, higher brain processes associated with intention and motivation (Masaoka et al. 2005) to inspire might be involved. Bensafi et al. (2005) reported that large sniffing volume while imagining a pleasant odor improved odor imagery and indicated an important link between inspiration activities and mental state. Slow and deep breathing, either automatic or intentional, can affect emotional state.

Advantage of slow and deep breathing

An increase in f_R coactivated with the AMG in a negative state increases attention and vigilance, which are defense mechanisms. Then what is the advantage of slow and deep breathing?

Deep breathing enables us to relax in stressful situations. Fontanini and Bower (2006) suggested that degree of synchronization across the entire cortical rhythm is specific during slow-wave sleep and might be organized by slow respiration. During slow-wave sleep, slow respiration indicates synchronization of the whole brain including the Pir, AMG, HI, and cortex (Fontanini and Bower 2006). The author speculates that humans have learned through slow breathing to induce a level of whole-brain synchronization that is naturally found only during slow-wave sleep. In the awake state, synchronization may occur at higher frequencies associated with experience and perception, even in a stressful state. Slow breathing may contribute to cleansing by whole-brain synchronization and may be related to meditation and refreshment of emotional state. Autobiographical pleasant odor memories unconsciously or even consciously associated with increased slow and deep breathing may influence whole-brain synchronization and assist in inducing comfortableness and pleasantness.

Slow and deep breathing is dependent on degree of individual subjective feelings and trait anxiety scores

Although every subject had increased V_T with a decrease in f_R elicited by an autographical pleasant odor memory, the degree of increase in V_T depended on anxiety trait scores and the strength of feeling back in time to the memory. High trait anxiety subjects responded with a stronger feeling of being taken back in time and had high arousal levels with V_T increases.

It has been reported that in a situation producing negative emotions such as anticipatory anxiety, high trait anxiety subjects tend to experience an increase in f_R (Masaoka and Homma 1997). Arousal level related to negative emotions has been correlated with anxiety trait scores (Masaoka and Homma 2001). In this study, we confirmed that emotional arousal and arousal level of the memory were correlated with anxiety scores. We assume that subjects with high anxiety tend to be influenced by outer stimuli, and both negative and positive emotions may be caused by high arousal

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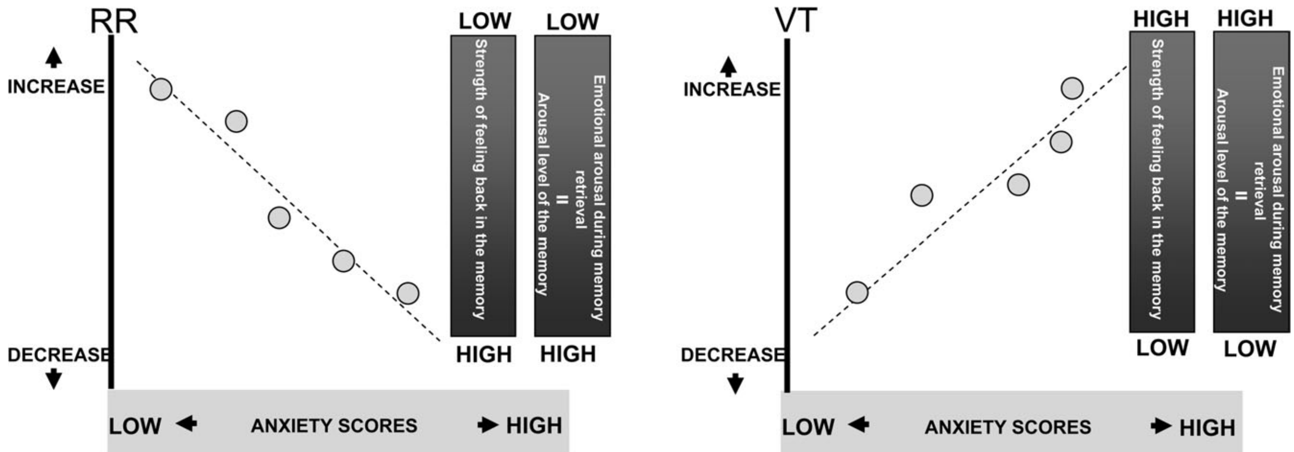

Figure 5 A schema for the relation between respiratory change, anxiety score, strength of feeling back in the memory, emotional arousal during memory retrieval, and arousal level of the memory. Subjects with high anxiety had decreased f_R with an increase in V_T and a strong feeling of being back in the memory, emotional arousal during memory retrieval, and high arousal level of the memory. Subjects with low anxiety showed an opposite pattern.

level accompanied with physiological responses. Figure 5 shows a schema for the relation between respiratory change, anxiety score, strength of feeling back in the memory, emotional arousal during memory retrieval and arousal level of the memory. Subjects with high anxiety had decreased f_R with an increase in V_T, and a strong feeling of being back in the memory, emotional arousal during memory retrieval, and high arousal level of the memory. Subjects with low anxiety showed an opposite pattern.

Odor-elicited autographical pleasant memories might be useful for relaxation in stressful situations, causing increased f_R in subjects with high anxiety by means of slow and deep breathing.

We examined only the link between an odor-evoked autobiographical pleasant memory and respiration in this study. It might be argued that odor-evoked autographical unpleasant memory and respiration should be tested. We paid careful attention if the odor identified by subjects caused retrieval of an unpleasant memory, with concern about possibly triggering symptoms of posttraumatic stress disorder. Because odors are tied closely to emotions and memory, we carefully considered the limitations of the experimental setup.

Mechanism of slow and deep breathing

Because odor is not visible or readable and is unshaped, the form of an odor is designed by image, emotions, and memory. Our question is this: What is the most pleasant odor among odors generally considered comfortableness? The present study suggests that feeling pleasant about an odor may be associated with the past experiences with a sense of comfortableness, familiarity, and even a realization of arousal toward this odor. These emotional feelings coexisting with slow and deep breathing involving higher brain processes may be peculiar to humans.

It is of interest to note that memory consolidation is considered to occur during slow-wave sleep (Rasch et al. 2007). Slow respiration synchronized with the whole brain during slow-wave sleep (Fontanini and Bower 2006) may not only be a factor related to the mechanism of mental meditation but may also play a role in fundamental memory processes. Based on these assumptions, we posit that autographical pleasant memories associated with slow and deep breathing may consolidate tightly during slow-wave sleep and be stored in long-term memory. If so, associating slow breathing with feelings of pleasantness related to odor-evoked autographical memory can be an efficient way to feel comfortable or relaxed in various stressful and negative situations.

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