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Original Paper

Effects of Olfactory Stimuli on Spontaneous Swallowing in Healthy Adults

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Abstract

Spontaneous swallowing plays a role in maintaining the ventilation of the upper respiratory tract by removing retained saliva. This study aimed to investigate whether olfactory stimulation with black pepper, peppermint, and lavender oil is effective in promoting spontaneous swallowing. We recruited 47 healthy adult participants. Spontaneous swallowing frequency, heart rate, and saliva volume were evaluated. The results showed that olfactory stimuli with peppermint and lavender oil significantly decreased the heart rate. No significant differences were observed in the frequency of spontaneous swallowing or saliva volume under any olfactory stimulus. However, olfactory stimulus with black pepper led to increased spontaneous swallowing frequency in more participants than other olfactory stimuli. Therefore, there might be individual differences in the improvement of the spontaneous swallowing function owing to olfactory stimulation with black pepper oil. Future studies are required to investigate the characteristics of individuals whose spontaneous swallowing function is improved by olfactory stimulation with black pepper oil and the underlying mechanism.

1. Introduction

Pneumonia is a major cause of death in Japan, and its mortality risk increases with age[1]. Aspiration is the most common cause of pneumonia in older individuals[1]. Aspiration pneumonia is defined as an infection in which the aspiration of oropharyngeal contents into the lower airway causes chemical pneumonitis and lung injury, resulting in bacterial infection[2]. Administration of antibiotics is an effective treatment for aspiration pneumonia[1] but may not be sufficient; therefore, approaches to prevent aspiration should be considered.

Spontaneous swallowing plays a role in maintaining the ventilation of the upper respiratory tract by removing retained saliva. One of the causes of aspiration pneumonia is the aspiration of saliva owing to a decline in the spontaneous swallowing function. Saliva containing bacteria and viruses can cause aspiration pneumonia upon reaching the trachea and lungs. Therefore, it is necessary to investigate approaches to improve spontaneous swallowing function.

There are various approaches to swallowing dysfunction, including dietary interventions using thickened

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liquids and behavioral interventions such as the Shaker head lift[3]. However, this approach to improve dysphagia is difficult to apply in individuals at risk of aspiration combined with very low activity or decreased consciousness[4]. Ebihara et al.[4] stated that aromatherapy is effective in preventing feeding and aspiration in such patients. It has been reported that olfactory stimulation with black pepper (BP) oil improves the swallowing reflex[5]. Ebihara et al.[5] reported that olfactory stimulus with BP oil improves the swallowing reflex when induced by using a 1-mL bolus of distilled water in post-stroke older patients. Olfactory stimulus with menthol solution for older people with dysphagia improves the swallowing reflex when induced by using a bolus injection of 1 mL of distilled water[6]. This study also suggests that Transient Receptor Potential Melastatin 8 receptors in the laryngopharyngeal region are involved in the mechanism by which menthol solutions improve the swallowing reflex[6]; however, the details remain unknown. Peppermint (PM) oil has a chemical structure similar to that of menthol and is an essential oil often used in aromatherapy. Contrastingly, olfactory stimulation with lavender (LV) oil has no effect on swallowing function[5]. Therefore, this study investigated whether olfactory stimulation with BP, PM, and LV oil improves spontaneous swallowing in healthy individuals.

2. Methods

2.1 Participants

Forty-seven healthy adults (11 males, 36 females, 20.8 ± 0.5 years) participated in this study. The purpose of the study was explained and written informed consent obtained. The participants had no olfactory or swallowing function impairments.

2.2 Procedures

A table was placed in front of the participant, and the participant was seated in a chair. An aroma diffuser was placed obliquely in front of each participant. The participants were instructed to relax during the experiment and were allowed to use smartphones and perform class-related tasks without speaking.

Spontaneous swallowing frequency, heart rate, and saliva volume were evaluated. Heart rate was measured to examine the effects of olfactory stimuli on autonomic nerve activity. In addition, the saliva volume was measured as it is considered to induce spontaneous swallowing.

Spontaneous swallowing was assessed as described by Tanaka et al.[7]. A laryngeal microphone (SH-12ik; Nanzu Electric Co., Ltd., Shizuoka, Japan) was placed slightly below the thyroid cartilage and outside the trachea (Figure 1A). The laryngeal microphone was connected to an IC recorder (Voice Trek DM-4; Olympus Corp., Tokyo, Japan) to record the swallowing sounds. The audio signal data were saved on a personal computer and visualized (Figure 1B). Spontaneous swallowing frequency within 20 min was

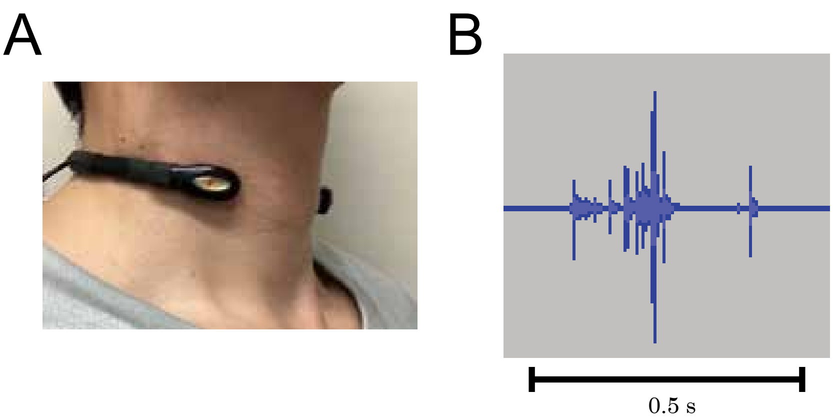

Figure 1 Measurement of spontaneous swallowing

A: The participant wearing a laryngeal microphone; B: Visualized swallowing sounds counted.

A wearable heart rate sensor (myBeat WHS-1, Union Tool Co., Tokyo, Japan) was used to measure heart rate. Two blue sensor electrode pads were attached to the heart rate sensor. The right blue sensor electrode was placed on the left side of the center of the body, 80-100 mm below the medial edge of the clavicle. The heart rate was measured for 20 min, and the average value was calculated.

Saliva volume was measured according to the method described by Funayama et al.[8]. The participants were asked to swallow and wipe off the saliva accumulated on the oral cavity floor using absorbent cotton. Subsequently, a cotton roll was placed on the oral cavity floor for 1 min. An electronic balance was used to measure the weight of the cotton roll. The saliva volume was obtained by subtracting the weight of the cotton roll from that of the cotton roll containing saliva.

In the experiment, we first measured saliva volume and then the frequency of spontaneous swallowing and heart rate. Saliva volume was measured again 20 min after the first measurement.

As olfactory stimuli, BP (Charis Seijo Co., Ltd., Tokyo, Japan), PM (Charis Seijo Co., Ltd., Tokyo, Japan), and LV oil (Charis Seijo Co., Ltd., Tokyo, Japan) were used. Olfactory stimuli were diffused using an ultrasonic aroma diffuser (AD-SD2; Ryohin Keikaku Co., Ltd., Tokyo, Japan). The aroma diffuser was filled with 100 mL of water, and two drops of each oil were added and diffused into the room. Forty-seven participants were randomly divided into three groups, which are the BP (n=15), PM (n = 16), and LV (n = 16) groups. Spontaneous swallowing frequency and heart rate were measured under olfactory stimuli. Subsequently, the saliva volume was measured.

2.3 Statistical analysis

SPSS Statics 26.0 (IBM Japan Inc., Tokyo, Japan) was used for statistical analysis. The significance level was set at $p < 0.05$. Statistical analyses were performed for the BP, PM, and LV groups for age, gender, and activity during the experiment. The Kruskal-Wallis test was used to compare the ages among the three groups. The relationship between gender or activity during the experiment and olfactory stimuli was analyzed using the chi-square test. Statistical analysis of spontaneous swallowing frequency, heart rate, and saliva volume between rest and under olfactory stimulation was performed using the Wilcoxon signed-rank test.

The chi-square test was conducted to analyze the relationship between olfactory stimuli and changes in spontaneous swallowing. An adjusted residual analysis was performed when a significant difference was observed in the chi-square test. Regarding the adjusted residual analysis, when the adjusted residue was +1.96 or more, it was judged to be significantly higher than other frequencies, and when it was -1.96 or less, it was judged to be significantly lower than other frequencies.

3. Results

3.1 Comparison of age, gender, and activity during the experiment between the three groups

Age, gender, and activity during the experiment were compared among the BP, PM, and LV groups. There were no significant differences in age among the three groups (Table 1). There were no significant differences in the proportions of females and males among the three groups (Table 1). The activities performed by the participants during the experiment were classified into three types: "performing class-related tasks,", "performing class-related tasks and using smartphones," and "using smartphones." There were no significant differences in activity during the experiment among the participants (Table 1).

3.2 Effects of olfactory stimulus on heart rate and saliva volume

Heart rate could not be measured in two participants in the BP group, four in the PM group, and two in the LV group because of difficulties in receiving heart rate data.

3.2.1 Olfactory stimulus of BP

Heart rate was 71.3 (66.5-78.9) bpm at rest and 69.3 (67.4-75.0) bpm under olfactory stimulus with BP, with no significant difference (Table 2). Saliva volume was 0.22 (0.18-0.47) g at rest and 0.23 (0.10-0.51) g under olfactory stimulus with BP, with no significant difference (Table 2).

Table 1 Comparison of age, gender, and activity during the experiment among the three groups

	BP	PM	LV	p value
Age	21(20-21)	21(21-21)	21(20.8-21)	0.669[a]
Gender (Male/Female)	5/10	3/13	3/13	0.626[b]
Activity (Ta/Ta+Sm/Sm)	9/5/1	7/1/8	10/3/3	0.056[b]

Data are presented as median (first-third quartile)
BP: black pepper oil; PM: peppermint oil; LV: lavender oil
Ta: class-related tasks; Sm: smartphone
a: Mann-Whitney U test with Bonferroni correction; b: chi-square test

3.2.2 Olfactory stimulus of PM

Heart rate significantly decreased to 77.3 (70.6-78.9) bpm under olfactory stimulus with PM compared with 79.4 (74.2-83.0) bpm at rest ($p<0.05$; Table 2). Saliva volume was 0.27 (0.20-0.38) g at rest and 0.29 (0.20-0.34) g under olfactory stimulus with PM, with no significant difference (Table 2).

3.2.3 Olfactory stimulus of LV

Heart rate significantly decreased to 78.0 (73.9-79.5) bpm under olfactory stimulus with LV compared with 82.1 (76.8-85.5) bpm at rest ($p<0.01$; Table 2). Saliva volume was 0.32 (0.06-0.49) g at rest and 0.35 (0.10-0.52) g under olfactory stimulus with LV, with no significant difference (Table 2).

3.3 Effects of olfactory stimuli on the number of spontaneous swallows

Compared with at rest, no significant difference in the frequency of spontaneous swallowing was observed for any olfactory stimulus (Table 2). Spontaneous swallowing frequency varied widely among the participants, and some participants showed extreme changes in spontaneous swallowing frequency during olfactory stimuli. To eliminate the influence of extreme numerical changes, statistical analyses were performed by classifying the changes in spontaneous swallowing frequency into categories.

Spontaneous swallowing frequency under olfactory stimuli was classified into three categories: "increased," "no change," and "decreased" compared with that at rest. A significant association was observed between the change in spontaneous swallowing frequency and the olfactory stimuli (chi square test, $p=0.05$, Table 3).

Table 2 Results of heart rate, saliva volume, and spontaneous swallowing frequency

		At rest	During olfactory stimulation	p value[a]
Heart rate	BP	71.3 (66.5-78.9)	69.3 (67.4-75.0)	0.196
	PM	79.4 (74.2-83.0)	77.3 (70.6-78.9)	0.034*
	LV	82.1 (76.8-85.5)	78.0 (73.9-79.5)	0.001**
Saliva volume	BP	0.22 (0.18-0.47)	0.23 (0.10-0.51)	0.367
	PM	0.27 (0.20-0.38)	0.29 (0.20-0.34)	0.409
	LV	0.32 (0.06-0.49)	0.35 (0.10-0.52)	0.509
Spontaneous swallowing frequency	BP	15.0 (6.5-17.0)	9.0 (6.0-16.5)	0.864
	PM	13.5 (10.0-15.3)	9.5 (8.0-12.5)	0.086
	LV	10.5 (5.8-16.5)	10.5 (5.8-12.0)	0.108

Data are presented as median (first-third quartile)
BP: black pepper oil; PM: peppermint oil; LV: lavender oil
a: Wilcoxon signed-rank test

Table 3 Frequency and adjusted residual by category of spontaneous swallowing

			BP	PM	LV	p value[a]
Spontaneous swallowing	Increase	Frequency	10	2	5	0.015
		Adjusted residual	3.0	-2.4	-0.5	
	No change	Frequency	0	3	1	
		Adjusted residual	-1.4	1.8	-0.4	
	Decrease	Frequency	5	11	10	
		Adjusted residual	-2.1	1.3	0.7	

BP: black pepper oil; PM: peppermint oil; LV: lavender oil
a: chi-square test

Regarding the difference in frequency, the adjusted residual analysis showed that the "increased" category in BP was 3.0, which was significantly higher than the other frequency categories (Table 3). Furthermore, the "decreased" category in BP was -2.1, which was significantly lower than the other categories (Table 3). Conversely, the "increased" category in PM was -2.4, which was significantly lower than the other categories (Table 3).

4. Discussion

Spontaneous swallowing removes the retained saliva and maintains ventilation of the upper airway. When the frequency of spontaneous swallowing decreases, saliva is retained in the upper airway, leading to breathing obstruction and aspiration, which may eventually lead to aspiration pneumonia. In this study, we investigated whether olfactory stimulations with BP, PM, or LV oil was effective in inducing spontaneous swallowing.

4.1 Three-group comparison of age, gender, and activities performed during the experiment

There were no significant differences in age, gender, or activity among the BP, PM, and LV groups during the experiment. Therefore, these items were regarded as samples with no differences among the three groups.

4.2 Effects of olfactory stimulus on heart rate

A statistically significant decrease in heart rate was observed in the LV and PM groups. Previous studies reported that olfactory stimulation with LV oil resulted in parasympathetic nerve activity becoming dominant and decreased heart rate[9]. The results of this study are consistent with those of a previous study, indicating that LV increases parasympathetic nerve activity and decreases heart rate. Sublingual administration of PM has been reported to decrease heart rate, whereas olfactory stimulation with PM does not decrease heart rate[10]. In this study, olfactory stimulation with PM decreased heart rate, which is different from that reported in the previous study. Thus, heart rate suppression by olfactory stimulation with the PM is controversial and should be investigated in future studies. In this study, olfactory stimulation with BP showed no significant difference in heart rate. A previous study reported that olfactory stimulation with BP prevents an increase in heart rate during acute stress reactions[11]; however, it has not been reported to decrease heart rate at rest. The therapeutic effects of BP have been attributed to physiological and psychological effects[11]. Since BP is generally recognized as a stimulant, the heart rate may be increased owing to a psychological effect when individuals perceive a strong odor[11]. In this study, no significant increase in heart rate was observed, suggesting that the participants did not perceive the olfactory stimulus to be strong.

4.3 Effects of olfactory stimulus on saliva volume

In this study, olfactory stimuli had no effect on saliva volume. Previous studies examining the relationship between BP and salivary secretion in healthy individuals reported that BP increases salivary secretion[12,13], and olfactory stimulation with LV promotes salivary secretion in healthy individuals[13]. However, no previous studies have investigated the effects of PM on salivary secretion. The effect of olfactory stimuli on saliva secretion remains controversial, and further investigation is required.

4.4 Effects of olfactory stimulus on the number of swallows

Previous studies on post-stroke older patients have reported that the olfactory stimulation with BP improves swallowing reflex induction[5]; however, no studies have been conducted on healthy individuals. Because swallowing function is normal in healthy individuals, there may be little room for improvement in swallowing function induced by BP. This study in healthy participants showed that the number of "increases" in spontaneous swallowing during olfactory stimulation with BP was higher than with other olfactory stimuli. In a previous study on post-stroke older patients, olfactory stimulation with BP improves the swallowing reflex by activating the insular or orbitofrontal cortex[5]. Although improvement was small in healthy individuals, a similar mechanism might increase spontaneous swallowing frequency. Furthermore, the insular cortex becomes more active during hunger, suggesting its involvement in promoting swallowing function[5]. Because BP is a spice used in dishes such as steaks, increasing appetite may promote swallowing function. Jelly containing menthol, a substance similar to PM, has been reported to promote the swallowing reflex[6]. However, no study has reported that olfactory stimulation with PM promotes swallowing function. In this study, olfactory stimulation with PM resulted in the lowest "increase" in spontaneous swallowing frequency in the adjusted residual analysis. In Japan, PM is often used in toothpaste and gums. As swallowing does not occur when brushing teeth or chewing gum, some participants may have learned that the PM scent does not promote swallowing. Olfactory stimulation with LV is reported to not improve the swallowing reflex[5]. The results of the present study, showing that LV exposure does not affect swallowing function, were similar to those of previous studies. Therefore, among these olfactory stimuli, BP had a relatively strong effect on promoting spontaneous swallowing.

4.5 Effects of olfactory stimuli on heart rate, saliva volume and the number of swallows

Olfactory stimulation with PM and LV resulted in a decrease in heart rate, which may be indicative of a relaxing effect. Although heart rate has been reported to increase when a BP scent is strong, no increase in heart rate was observed in the present study. Olfactory stimulation with PM and LV was accompanied by a parasympathetic-dominant relaxing effect, and olfactory stimulation with BP did not show a sympathetic-dominant increase in heart rate. These results suggest that they do not impose a load on the circulatory system.

No significant differences in saliva volume were observed in response to any olfactory stimuli. Spontaneous swallowing was shown to increase more frequently with BP than with the other olfactory stimuli. Based on these results, participants who exhibited an "increase" in spontaneous swallowing during olfactory stimulation with BP were likely to be affected by a central rather than a peripheral effect associated with increased saliva volume.

5. Conclusion

In this study, we investigated the effects of olfactory stimulation with BP, PM, and LV on spontaneous swallowing. The results showed that olfactory stimulation with BP promoted spontaneous swallowing. However, as individual differences such as psychological factors also have an effect, it is necessary to examine the influences of preferences and life history. The establishment of a therapeutic method using BP as an olfactory stimulus will expand treatment options for people who are at risk of aspiration, are very inactive or who have reduced consciousness. Therefore, it is necessary to investigate the characteristics of individuals whose spontaneous swallowing function is improved by olfactory stimulation with BP and the mechanisms involved.

Ethical considerations

This study was approved by the ethics committee of Kawasaki University of Medical Welfare (14-055) and was then conducted in accordance with the committee's guidelines.

Conflicts of interest

There are no conflicts of interest to declare regarding this research.

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