Physiological and Psychological Response to Floral Scent

Hyunju Jo¹ and Susan Rodiek

Department of Architecture, Center for Health Systems & Design, Texas A&M University, 3137 TAMU, College Station, TX 77843-3137

Eiji Fujii

Graduate School of Horticulture, Chiba University, 648 Matsudo, Chiba, 271-8510, Japan

Yoshifumi Miyazaki

Center for Environment, Health and Field Sciences, Chiba University, 6-2-1 Kashiwanoha, Kashiwa, Chiba, 277-0882, Japan

Bum-Jin Park

Department of Environment & Forest Resources, Chungnam National University, Daejeon, Chungnam, 305-764, Korea

Seoung-Won Ann

Department of Horticulture, Kongju National University, Yesan, Chungnam, 340-800, Korea

Additional index words. people–plant interactions, human issues in horticulture, fragrance, cerebral and autonomic nervous system activities, semantic differential scale, profile of mood states

Abstract. To better understand how fragrance may enhance human health, this study examined psychophysiological responses to Japanese plum blossom fragrance. Although previous studies used essential oils or fragrance components, the present study measured the effects of floral scent naturally diffused by the plant itself to simulate the way we generally experience natural scent in everyday life. Subjects were Japanese males ($n = 26$), and the data collected included cerebral and autonomic nervous system activities, semantic differential (SD) scale, and profile of mood states (POMS). Exposure to the fragrance significantly activated the sympathetic nervous system and the cerebral areas related to movement, speech, and memory. SD scale and POMS results showed the fragrance evoked cheerful, exciting, and active images and changed mood states by enhancing vigor while suppressing feelings of depression. These findings indicate that contact with a floral scent such as plum blossom fragrance can improve mood states and may foster the brain functions of memory, speech, and movement, potentially leading to improvements in emotional health, depression, and memory disorders.

Contact with plants has been found to be associated with health benefits, including improvements in physical, cognitive, psychological, and social functioning (Simson and Straus, 1998). The people–plant relationship has been explored in terms of theoretical concepts such as learning, evolution, and overload/arousal (Kaplan and Kaplan, 1989). For example, the evolution theory maintains that because we evolved in environments consisting primarily of plants, we tend to have positive psychological and physiological responses to them (Frumkin, 2001; Ulrich, 1983). Increasingly, empirical studies demonstrate that people tangibly benefit from contact with plants

and other nature elements using different kinds of measures in different populations (Kuroko and Fujii, 2002; Rodiek, 2002; Ulrich 1981, 1984). These studies show that passive or active involvement with nature such as gardening or viewing/experiencing a natural setting can have a positive impact on physical and mental health. These findings can be applied to the design of improved environments; they can also be used in therapeutic horticulture to create more effective healing experiences (Cooper Marcus and Barnes, 1999; Gonzalez et al., 2010).

Although there is empirical evidence of the restorative effects of nature and plants, a majority of studies have focused on either visual perception of nature (Chang and Chen, 2005; Parsons et al., 1998; Ulrich et al., 1991) or else active involvement with plants (McBey, 1985). However, therapeutic horticulture professionals have documented the importance of the non-visual sensory perceptions such as scent, sound, touch, and taste. Some have suggested that a sensory or memory garden

should stimulate as many senses as possible by using natural elements such as sunlight, water, breezes, fragrance, and views of wild-life (Wagenfeld, 2009). Multisensory stimulation has been found to enhance the healing effects of nature, especially for specific users such as children, hospital patients, and persons with dementia (Chapman et al., 2005; Said and Abu Bakar, 2007).

In a nature setting, people may experience plant scents consciously or unconsciously. Gardens may be designed to take advantage of attractive floral scents, which may create feelings leading to specific kinds of therapeutic experience. Floral scents can often trigger memories of particular times, events, places, or feelings (Haas and McCartney, 1996). Studies of the brain have shown that the olfactory sense is closely related to the limbic system, which in turn is responsible for the function of instinct. The olfactory sense is also intimately related to mood and feelings and, unlike the other senses, is linked to long-term memory (Brennan et al., 1990; Engen, 1982; Herz et al., 2004; Onoda, 2000; Zatorre et al., 1992). The aspects of the olfactory sense relating to emotion and memory suggest the possible therapeutic benefits of floral scent. As a potential natural healing element, floral scent may provide substantial mental or emotional benefits such as relieving anxiety or depression and maintaining memory abilities for individuals with Alzheimer's disease or other memory disorders (Brawley, 2004; Cohen-Mansfield and Werner, 1999).

By measuring cerebral and autonomic nervous system responses, studies have demonstrated the physiological responses resulting from fragrances; for example, lavender fragrance increased beta power in electroencephalographic activity, suggesting increased drowsiness and also increased parasympathetic nervous activity in the direction associated with relaxation. Rosemary fragrance, on the other hand, decreased alpha and beta power, suggesting increased alertness; it also stimulated sympathetic nervous activity associated with excitement (Diego et al., 1998; Saeki and Shiohara, 2001). However, a majority of these studies has used essential oils or fragrance components instead of actual plant materials. Few previous studies have examined the effect of the scent that is naturally diffused by the plant, which is generally how we experience scent in everyday life or in horticultural activities. Kweon et al. (2003) compared the brain responses between people who were tearing peppermint leaves compared with people who were tearing paper and found those handling peppermint showed more vigor and brain stimulation than those handling paper. Interestingly, by comparing brain responses with intuitive verbal responses to the same scent, Jo et al. (2007) found that familiar plant scents such as *shiso* (*Perilla frutescens*) and Japanese pepper tree leaves (*Zanthoxylum piperitum*), often used as foods or medicines, are typically thought of as stimulating, whereas they actually have a relaxing effect on the prefrontal area in the cerebrum involved in judgment and feeling

Received for publication 19 Apr. 2012. Accepted for publication 7 Nov. 2012.

We appreciate the valuable contributions of the students at Chiba University in Japan, who were willing to participate in the experiment.

¹To whom reprint requests should be addressed; e-mail hjo1011@gmail.com.

function. These studies suggest that the natural scent diffused by plants can have positive physical and mental benefits that may be useful in horticultural therapy.

The present study measured the immediate effects of natural floral scents on the cerebrum and autonomic nervous system as well as on psychological evaluations of mood and stimuli using the scent diffused by the flower itself. The findings presented here may lead to better understanding of how fragrance affects people in indoor and outdoor gardens, therapeutic environments, or during horticultural activities.

Materials and Methods

Participants and experimental setting.

The participants were 26 Japanese male students in their mid-20s (mean age $\pm$ SD, 24 ± 1.8 years) recruited from landscape and horticulture programs at Chiba University in Japan. This limits the generalizability of the study but had the advantage of reducing differences of olfactory response resulting from gender, age, and culture. Undergraduate and graduate volunteers were recruited by a flyer, and informed consent was obtained according to the regulations of the Human Investigation Committee of Chiba University. Interviews were used to screen those with relevant past or current physical and olfactory disorders such as insomnia or sinus infection with the potential to influence the physiological results. The experiment was conducted in a screened room at Chiba University, where subjects would be exposed to the fewest external influences and go through the test under the same conditions. In the middle of a shielded room (59.4 m²), with a white ceiling and walls, a chair was set for the subject. The biological measurement devices were placed behind the chair to reduce visual influences. A 77 °F temperature and 60% relative humidity were maintained throughout the experiment, because the concentration of scent alters with changes in temperature and humidity (Bocca and Battiston, 1964).

Scent stimulus. The present study used the scent of Japanese plum blossoms (ume, or *Prunus mume*). The Japanese plum tree has traditionally been used as a garden plant and bonsai material, because of the beautiful flowers and fragrance of the blossoms (Horiuchi, 1996). For this study, the fragrance was obtained from the fresh petals collected a few hours before the experiment. Four grams of petals (≈ 36 petals, considered to emit an appropriate concentration of scent) and odorless air were put in a polypropylene bag. The scent was then allowed to concentrate naturally within the bag. The same type of odorless air was placed in a bag without plum blossom petals as a comparison for the plum blossom-scented air. To present the same concentration and intensity of scent to all subjects, to the extent possible, the scent and odorless air were presented using the process illustrated in Figure 1. Because the olfactory sense has a wide range of individual differences,

the perceived intensity of the fragrance was evaluated ranging from odorless to intolerable (range of intensity: 0 to 4 = odorless to faint; 4 to 8 = faint to weak; 8 to 12 = weak to strong; 12 to 16 = strong to very strong; 16 to 20 = very strong to intolerable). As a result of this method of evaluation, the plum blossom fragrance was reported as having an intensity between weak and strong (mean $\pm$ SD, 9.34 ± 3.5), whereas the odorless air was evaluated as almost odorless (mean $\pm$ SD, 1.23 ± 1.58).

Measures. The study used a combination of biological measures and verbal responses. While each subject was exposed to the fragrance, cerebral and autonomic nervous system activities were recorded. After taking biological measurements, verbal evaluations were used to determine the subject's mood, mental images, and the emotional qualities evoked by exposure to either the plum blossom fragrance or the odorless air.

Cerebral activity. Changes in cerebral activity resulting from the scent stimuli were measured by multichannel near-infrared spectroscopy (NIRS; OMM-2001; Shimadzu Co., Ltd., Japan). Unlike contingent negative variation) or electroencephalogram, which use minute magnetic fields occurring from ion electronic charges in the cerebral blood, NIRS directly monitors regional relative changes of hemoglobin concentration in the cerebral blood flow (Villringer and Dirnagl, 1995). This method requires only compact experimental systems and is less restrictive, allowing the subject to move or be active in his or her seat, unlike functional magnetic resonance imaging) and positron emission tomography testing, which require subjects to remain in a supine position (Nakamura, 1996; Okamoto et al., 2004). Measurement was limited to the right brain hemisphere as the

seat of activities related to emotions and image creation (Silberman and Weingartner, 1986; Tucker, 1981; Fig. 2A). A total of 47 measurement locations, referred to as channels (e.g., ch10, ch17, ch24), were located in the frontal, parietal, temporal, and occipital lobes (Fig. 2B). These brain locations correspond with feeling, judgment, premotor, motor, somatosensory, cognition, visual, auditory, and memory functions and indicate how the fragrance influenced subjects' memory and emotions (Caplan, 1993; Shepherd, 1901; Fig. 2C).

Autonomic nervous system activity. The autonomic nervous system is related to functions that are necessary for life such as respiration, heart rate, and blood pressure. Autonomic nervous system response indicates shifts in psychological factors such as emotion, motivation, attention, and preference as well as physical movement (Harmon and Beer, 2009). There are two main parts: the sympathetic nervous system (SNS) and the parasympathetic nervous system (PNS). In general, the SNS is activated by excitement and tension, which are accompanied by increased heart rate and blood pressure. The PNS is activated by relaxation and is associated with slower heart rate and decreased blood pressure (Robertson, 2004). For this study, a finometer device, which clips on the middle finger of the left hand (Fig. 3), was used to measure pulse rate and arterial blood pressure. The device can sequentially measure blood pressure and pulse rate during exposure to the scent stimuli and is less burdensome to the subjects as a result of the simplicity in wearing the device (Schutte et al., 2004). Three sensors attached to the chest (right collarbone; right and left ribs) were used to detect heart rate variability (HRV), as measured by an ambulatory

Fig. 1. Preparation and presentation process of plum blossom fragrance and odorless air. The scent stimuli were prepared as follows: (A) plum blossom fragrance: 4 g of plum blossom petals and odorless air were put into a polypropylene bag. The scent was then allowed to concentrate naturally within the bag; and (B) odorless air: into the same type of polypropylene bag, only odorless air was introduced as a comparison for the plum blossom-scented air. To present the same concentration and intensity of scent stimuli to all subjects, they were presented as follows: constant speed of the air ($3 \text{ L} \cdot \text{min}^{-1}$) was put into a pressure container that contained the plum blossom fragrance bag or odorless air bag by an air pump with a manometer attached, emitting a consistent volume of plum blossom fragrance or odorless air. All participants were asked to inhale the scent at a distance of 10 cm from their nose.

Fig. 2. Measurement of cerebral activity using multichannel near-infrared spectroscopy (NIRS). (A) The photograph shows the measurement of cerebral activity in the right brain hemisphere by the NIRS device. (B) The cerebral activity was detected in a total of 47 areas in cerebral cortex using electrodes (emitter and detector) of near-infrared light. The channel is the area between emitter and detector and indicates the location of cerebral activity. The 47 channels were located in the frontal, parietal, temporal, and occipital lobes. (C) According to the theory of localization of the brain function, 47 channels corresponded with feeling (ch1, 3), judgment (ch2, 4, 5, 6, 8, 9), premotor (ch7, 11, 12, 16), motor (ch13, 17, 18, 20, 21), somatosensory (ch22, 25, 26, 27, 29, 30, 31, 34, 35), memory (ch15, 19, 23, 24, 33), cognition (ch38, 39, 40, 41, 43), visual (ch42, 44, 45, 46, 47), auditory (ch28, 32, 36, 37), and speech (Broca, ch10, 14) functions.

electrocardiogram (AC-301A; GMS Corp., Japan). This method registers beat-to-beat variation in the heart rhythm, which reflects subtle changes in a person's emotional state

with great sensitivity (Kobayashi et al., 1999).

Mood and stimuli evaluations. To better understand how subjects responded to the

Fig. 3. (A–C) Measuring brain activity and other physiological responses during exposure to stimuli.

fragrance, two self-report questionnaires were introduced. First, mood was measured with the Profile of Mood States (POMS), which is a psychological rating scale that assesses short-term and distinct mood states (Pollock et al., 1979; Tsunetsugu et al., 2005). A brief version comprised of 30 items was used to reduce the time required for the measure (Profile of Mood States–Brief Form Japanese Version, Saccuss Bell Co., Ltd., Japan). The items were rated on a 5-point scale ranging from “not at all” to “extremely” and included six types of mood states: tension–anxiety (T-A), depression–dejection (D), anger–hostility (A-H) as well as fatigue (F), vigor (V), and confusion (C), as shown in Figure 7; in each case, a higher score indicates the subject is reporting higher levels of that mood state. The direct impressions evoked by the fragrance were examined using semantic differential (SD) methods, which have been found to be a reliable and valid way to quantify subjective feelings about external stimuli (Kang and Zhang, 2010; Lee et al., 2011; Snider and Osgood, 1969). In this study, 15 pairs of contrasting adjectives (e.g., artificial–natural, rough–delicate, woody–non-woody) were rated on a 7-point scale (Jo et al., 2007).

Experimental procedures. Figure 4 describes the overall experimental protocol, which took place over a 40-min period. After explaining the study details and protocol to each participant, the physiological measurement devices such as NIRS, HRV, and pulse rate/blood pressure and scent-emitting device were attached. The participant was then asked to relax fully during a rest period of ≈1 to 2 min with eyes closed to adjust his mood to the experimental atmosphere. After the NIRS monitor confirmed that cerebral activity was stable, the plum blossom fragrance was presented for 2 min based on

studies showing the olfactory adaptation phenomenon, in which sensory nervous activities decrease gradually when an odorant presents continually (Dalton, 2000). The presentation of scent stimuli was carried out without announcing that it was being done. During this time, physiological responses were measured, and questionnaires on the SD scale, POMS, and scent intensity were filled out. Although the written questionnaires took ≈ 5 min to complete, the fragranced air was presented only for the first 2 min. Then, the odorless air was presented for 2 min, also without being announced, and the same physiological and questionnaire responses were collected. The order was random with half the subjects receiving the fragrance first and half receiving the odorless air first.

Data analysis. The physiological changes during exposure to the fragrance were examined by comparing the means of each 30-s interval starting with the last 30 s of the rest period before fragrance presentation (Fig. 5).

This was assumed to represent the most stable states of the brain and physiological activity during the rest period. A paired t test (two-sided) was used to compare the physiological changes between rest and exposure periods. The cerebral activity analysis used changes in oxygenated hemoglobin (oxyHb) as the index of cerebral changes, where increased oxyHb is associated with increased cerebral activity. The changes were separately computed in 47 measurement locations of the brain. The HRV data were divided into 30-s segments, and the beat-to-beat intervals were analyzed by the maximum entropy method. The program was set with the variance of the low-frequency (LF) band at 0.04 to 0.15 Hz, and the variance of the high-frequency (HF) band at 0.15 to 0.4 Hz. The HF data were used as an index of parasympathetic nervous system activity, and the LF/(LF + HF) ratio was used as an index of sympathetic nervous activity (Lee et al., 2011). Because of the lack of normal distribution, the Wilcoxon signed-rank test (two-sided) was

used to verify the differences in psychological effect assessed by the SD scale and POMS between the fragrance and odorless air. SD data were analyzed by comparisons of rating scores between the fragrance and odorless air in each contrasting item. POMS analysis was conducted as the rating scores of six types of mood states calculated as T-scores according to the calculation method standardized by POMS (Yokoyama et al., 1990). Statistical validity was established at $P < 0.05$.

Results

Physiological responses. Figure 5 shows the time-series changes in oxyHb concentration, indicating cerebral activity during exposure to the fragrance and the odorless air in ch10 and ch24. Among 47 channels, the increases of oxyHb concentration by the fragrance exposure were significantly observed at three channels: ch10 (60 to 90 s, $P = 0.010$), ch17 (30 to 60 s, $P = 0.006$), and ch24 (60 to 90 s, $P = 0.018$; 90–120 s, $P = 0.024$), unlike

Fig. 4. Timeline (in minutes) of the physiological and psychological measurement during exposure to plum blossom fragrance and odorless air. The order was randomly reversed for half the subjects.

Fig. 5. Time-series changes in oxygenated hemoglobin (oxyHb) concentration (cerebral activity) during exposure to plum blossom fragrance and odorless air.

the odorless air, which did not show a clear change in any channels (Table 1). Considering the localization of the functions in the brain (Fig. 3C), the activated channels were located in the motor area (ch17), Broca's area related to speech function (ch10), and the memory area (ch24). In the autonomic nervous system responses, blood pressure and pulse rate did not show any clear changes on exposure to the fragrance and odorless air (data not shown). However, HRV results showed significant physiological changes with exposure to the fragrance. Starting with exposure to the fragrance, the LF/(LF + HF) ratio reflecting SNS activity was gradually increased compared with the rest period (–30 to –1 s) with significant increases observed during 31 to 60 s and 61 to 90 s at $P < 0.05$ (Fig. 6). Furthermore, cerebral and SNS responses both showed clear changes after 30 s of exposure to the fragrance and the effect lasted for 30 to 60 s; these results indicate that somewhat consistent exposure to the fragrance is needed to obtain clearer physiological effects of the fragrance.

Mood and stimuli evaluations. Figure 7 shows the changes in mood states by exposure to the fragrance and odorless air; compared with odorless air, exposure to the fragrance resulted in a lower depression–dejection score (D, $P < 0.05$) and a higher vigor score (V, $P < 0.01$). These results indicate that the fragrance enhanced positive feelings such as vigor, whereas it reduced negative feelings such as depression. The SD results found that the fragrance evoked various positive impressions, showing significant differences in 13 adjectives (Fig. 8). The fragrance was evaluated as being natural, rural, woody, active, cheerful, stimulating, exciting, distinctive, pleasant, and dense ($P < 0.01$); also firm, refreshing, and liked ($P < 0.05$). It is considered that impressions such as cheerful, exciting, active, and pleasant are related to the higher vigor scores found in the POMS test.

Discussion

In recent decades, as the importance of contact with plants has become more apparent, researchers have increasingly demonstrated the health benefits of plants using a wide range of methods, measures, hypotheses, and populations. A great deal of research has focused on visual perception and horticultural activity, whereas there are relatively few studies on non-visual effects of plants through sensory perception such as scent, sound, or touch, although multisensory stimulation has been identified as an important way to enhance the healing effects of nature. The fragrance of plants, consciously or unconsciously experienced during contact with plants, can affect our mood and feelings directly because the olfactory sense is intimately connected to the limbic system, which is in charge of instinctive aspects such as feeling and appetite in the brain.

The present study demonstrated some of the potential benefits of exposure to floral

Table 1. Brain channels^a that observed significant changes in oxygenated hemoglobin (oxyHb) concentration among 47 channels during exposure to plum blossom fragrance and odorless air.

	Plum blossom fragrance				Odorless air				(s)
	0–30	30–60	60–90	90–120	0–30	30–60	60–90	90–120	
ch10	0.004 NS	0.009 NS	0.010*	0.009 NS	–0.001 NS	0.006 NS	0.002 NS	0.005 NS	
ch17	0.002 NS	0.006*	0.003 NS	–0.002 NS	–0.007 NS	0.008 NS	–0.002 NS	–0.010 NS	
ch24	0.004 NS	0.010 NS	0.018*	0.024*	–0.000 NS	0.003 NS	0.007 NS	0.013 NS	(mm)

^aThe brain channel indicates the measurement location where near-infrared spectroscopy electrodes were placed. They were placed on 47 total areas in the right brain hemisphere. The means were compared between the rest period (–30 to –1 s) and the exposure period (every 30 s) to the fragrance and to the odorless air. Significant changes in oxyHb concentration were verified by paired t test (two-sided).

*Significant increase in oxyHb concentration at $P < 0.05$. NS = nonsignificant difference.

Fig. 6. Time-series changes in sympathetic nervous system activity during exposure to plum blossom fragrance and odorless air. Paired t test (two-sided) comparison of the means between the rest period (–30 to –1 s) and the exposure period (every 30 s) to the fragrance and odorless air. *Significance at $P < 0.05$. Mean $\pm$ SE.

Fig. 7. T-score for the Profile of Mood States (POMS) with plum blossom fragrance and odorless air. T-A = tension–anxiety; D = depression–dejection; A-H = anger–hostility; F = fatigue; C = confusion; V = vigor. Comparison of means between the plum blossom fragrance and odorless air; significant differences were verified by Wilcoxon signed-rank test (two-sided). * **Significance at $P < 0.05$ or < 0.01 , respectively. Mean $\pm$ SE.

Fig. 8. Mean score of semantic differential (SD) scale with fragrance and odorless air. The SD scale was used to evaluate the direct impressions evoked by plum blossom fragrance and odorless air using 15 pairs of contrasting adjectives on scales ranging from -3 to 3. The mean scores indicated the impressions of fragrance and odorless air, and significant differences were verified by Wilcoxon signed-rank test (two-sided). * **Significance at $P < 0.05$ or < 0.01 , respectively; Mean $\pm$ SE.

scent naturally diffused by flowers and verified multiple physiological and psychological responses using biological and verbal measures. Physiologically, the fragrance activated the cerebral areas in charge of movement, speech, and memory functions and stimulated the SNS activity in ways related to excitement. These results indicate that experiencing a floral scent such as plum blossom potentially can foster brain functions such as movement, speech, and memory and evokes a physiological effect similar to excitement. The finding of cerebral function activation is comparable with the results of previous research, in which the cerebral area in charge of speech was activated by exposure to pine scent (Jo et al., 2010). This helps to support earlier findings that involvement with plants through horticultural therapy tended to promote speech, communication, and thereby social interaction of participants with acquired aphasia and helped prevent deterioration of the mental abilities of individuals with Alzheimer's disease in long-term care (D'Andrea et al., 2007; Sarno and Chambers, 1997).

Psychologically, the plum blossom fragrance enhanced vigor while reducing depressed feelings and evoked cheerful, exciting, and active images. This helps explain the common experience that plant fragrances have a positive effect on our mood and emotions. It also supports the findings of previous studies on the benefits of plants such as the use of scented plants in horticultural activity or improvements found in mental and physical health through experiencing

fragrance (Cooper Marcus and Barnes, 1999; Gonzalez et al., 2010; Wichrowski et al., 2005).

Limitations of the study. To reduce confounding variables, this experiment controlled the gender, age, and nationality of participants as well as environmental conditions such as noise, temperature, and humidity (Bocca and Battiston, 1964; Brand and Millot, 2001). Accordingly, the effects found in this study might not be generalizable to certain populations or different environmental conditions. This study also did not find the distinct benefits of lowered blood pressure and pulse rate that have been found in previous studies (e.g., Bensafi et al., 2002). This might have been because previous studies typically used longer exposures and stronger fragrances derived from aromatic oils rather than natural plant scents. Further studies are needed to test outcomes with a wider range of participants and methodologies as well as using a longer presentation time, collecting data on the response time of the cerebral region and possibly on the subject's thoughts and feelings during exposure to the fragrance. It would also be valuable to verify the effect of scents while simultaneously viewing nature elements, like in the situations we experience in everyday life.

Conclusion

This study's findings on the physiological and psychological effects of floral scent support common experiential knowledge of

the effects of fragrance on humans and provide evidence that benefits of contact with plants are derived from not only through visual perception, but also through other sensory means such as olfactory perception. This strongly suggests that therapeutic use of plants should target multiple senses for optimal impact on physical, mental, and psychological health conditions.

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