Effect of eating sequence of nutritionally matched soups containing different flavors on frontal cortex blood flow and respiratory cardiovascular systems

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Abstract: This research studied the physiological effects of eating two nutritionally equivalent but differently flavored soups in different sequences. A randomized crossover study was performed in ten healthy men aged from 22 to 24. Two types of soup were used for the experiment. One was a commercially available nourishing soup (C soup), with nutritional contents similar to the liquid meals used in hospitals. The second soup had reduced flavoring and is referred to placebo soup (P soup), although it was nutritionally equivalent to the C soup. Subjects consumed 100ml of C or P soup, both of which were heated to 60 degrees, on different days. We measured the physiological effects and palatability of the two different-flavored soups (termed 'rich' and 'weak'). Subjects' taste impressions, cardiovascular respiration and frontal cortex blood flow were evaluated. Comparisons were made between the consumption of 'rich' flavored soup only; and the consumption of 'rich' flavored soup after drinking 'weak' flavored soup first. It was found that such a sequence had a noticeable effect on the subjects' heart rate, tidal volume, respiratory quotient, and frontal left side O2 hemoglobin. However, reverse comparisons between consuming the 'weak' flavored soup only, and drinking 'weak' soup and 'rich' flavored soup did not result in any noticeable effects. These findings suggest that the order of consumption of' rich' flavored soup has a noticeable effect on human metabolism.

Key words: Order effect, flavors, human metabolism

1. Introduction

It is known from previous research on the sequence of meals that what was eaten for breakfast will affect the blood sugar level on lunch as a second meal effect [1]. Moreover, when a vegetable salad (fiber rich food) is eaten first followed by rice (non-fibrous, carbohydrate rich food), blood sugar levels decrease more than if the two foods are eaten in the inverse sequence. This research examines the effects of eating foods in different sequences on the body. Generally, if there is nutritional equivalency in the different foods, then it is expected that the sequence in which they are eaten should have no notable effect on human metabolism. However, there has been no research into palatability and metabolism. So, this research estimated the palatability and the resulting respiratory metabolism for two soups with nutritional equivalency but different flavor strengths (termed 'strong' and 'weak'). Moreover, we also investigated what effect on metabolism the sequence the soups are consumed may have.

2. EXPERIMENTAL

2.1 Procedure

We first obtained approval for our experiment from the relevant Ethics Committee at our present institution. We also explained the purpose and methodology of the experiment to the subjects beforehand and gained their informed consent to participate. Eating was forbidden from the previous day and drinking was forbidden 6 hours before the start of the experiment. The experiment was conducted in a room with a controlled environment where the room temperature was set at 24 ˚C, with 55.5% humidity. The experiment took a total of 27 minutes: an initial resting stage of 5 minutes, 2 minutes for drinking the soup, followed by a recovery period of 20 minutes (Fig.1). As can be seen in Fig. 2, the experiment subjects, ten healthy men aged from 22 to 24, remained seated throughout.

Two types of soup were used for the experiment. One was a commercially available corn soup (C). The second soup had reduced flavoring though was nutritionally equivalent to the corn soup (Table 1). This was designated the placebo soup (henceforth P). 5 minutes after the experiment began, different subjects consumed 100ml samples of the different soups, which were heated to 60 ˚C and consumed by the subjects within 2 minutes.

In order to investigate the influence of the different sequences in which the two soups were consumed, we divided the subjects into two groups of five people, and experimented in the order of (P) -> (C), or (C) -> (P) the first time; and then in inverse order the second time. The subjects wore masks to measure for respiratory metabolism which was measured for 20 minutes after soup ingestion. Moreover, immediately after soup ingestion, we performed a seven scale organic-functions evaluation using SD, and a questionnaire survey to determine subjects' attitude to the taste of the soup using "pleasant" and "delicious" was conducted.

Table 1: The two soup's nutritional information.

Nutrition	C	P
Energy(kcal)	106	104
Protein(g)	5.3	5.3
fat(g)	3.6	3.3
Carbohydrate(g)	11.2	11.5
Dietary fiber(g)	3.6	3.8
Sodium(mg)	330	323

Fig. 1. Experiment scene

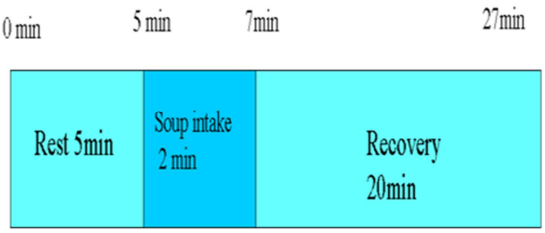

Fig. 2. Schedule for soup experiment.

2.2 Measuring Equipment, Data analysis and Statistical analysis

The equipment used for measuring the changes in the respiratory metabolism was a Quarkb2 (Bertec Japan). Evaluation of the data was based on the subjects' Energy Expenditure (EEm), and a Near Infrared Spectroscope NIRO-200 (Hamamatsu Photonics K.K) was used to measure the blood flow to the brain (O2Hb). Quarkb2

(COSMED srl) was used to measure respiratory metabolism, determining VO2 (oxygen uptake) and VCO2 (carbon-dioxide emissions). It also measured heart rate, energy consumed, and the respiratory quotient (VCO2/VO2). Using the respiratory metabolism measuring device, the measured value recorded for every breath was equalized for each minute, and the relative value was computed by making the measurement for [quiet] 5 minutes into the standard value. Average value was shown in the graph. A statistical analysis, using t official approval which has correspondence about organic-functions evaluation, about the vital reaction, analysis of variance was conducted between soup, and it divided every 10 minutes after ingestion, and authorized using the Bonferroni method. The significance level was set to $p < 0.05$.

3. RESULTS

3.1 Flavor impression

CP refers to the sequence in which corn soup (C) is ingested first, followed by the placebo soup (P). PC refers to the inverse order. The subjects ranking of the soups as 'pleasant' is shown in Fig. 3 on the left. ( ) is the average value. A high score corresponds to a favorable impression. C is significantly higher than P, CP (5.8 vs 3.2, 2.5). Also, PC is significantly higher than P, CP (5.3 vs 3.2, 2.5). For delicious ranking C is significantly higher than P, CP (5.8 vs 3.1, 2.7). Similarly, PC is significantly higher than P, CP (5.3 vs 3.1, 2.7) as shown in Fig. 3 on the right.

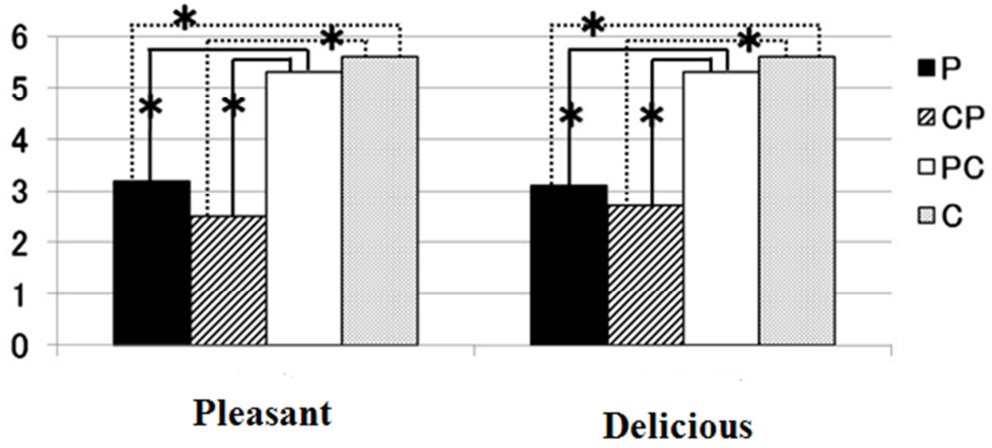

Fig. 3. Sensory profile of each soup. Data are mean value. (*: $p<0.05$).

3.2 Metabolism

A significant difference in energy expenditure after soup ingestion was not seen in either of the combinations (C vs. PC, P vs. CP). Figures 4 and 5 show changes in the heart rate (HR) after soup ingestion. C decreased significantly compared to PC during the 20 minute recovery period ($p < 0.01$). However, there was no significant difference observed in the comparison between P vs. CP. Figures 6 and 7 show changes in the respiratory quotient after soup ingestion. C decreased significantly compared to PC during the recovery period ($p < 0.01$). However, there was no significant difference observed in the comparison between P vs. CP. Figures 8 and 9 show changes in the one time ventilation (VT) after soup ingestion. C decreased significantly compared to PC during the 20 minute recovery period ($p < 0.01$). However, there was no significant difference observed in the comparison between P vs. CP.

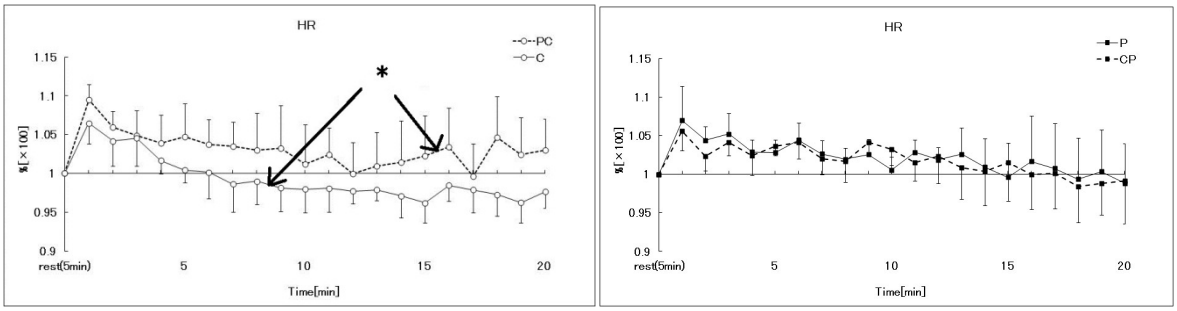

Fig. 4. Changes in heart rate after soup intake, (C) and (PC) comparison. Data are means ± SD, two-way ANOVA (*: p <0.01). Fig. 5. Changes in heart rate after soup intake, (P) and (CP) comparison.

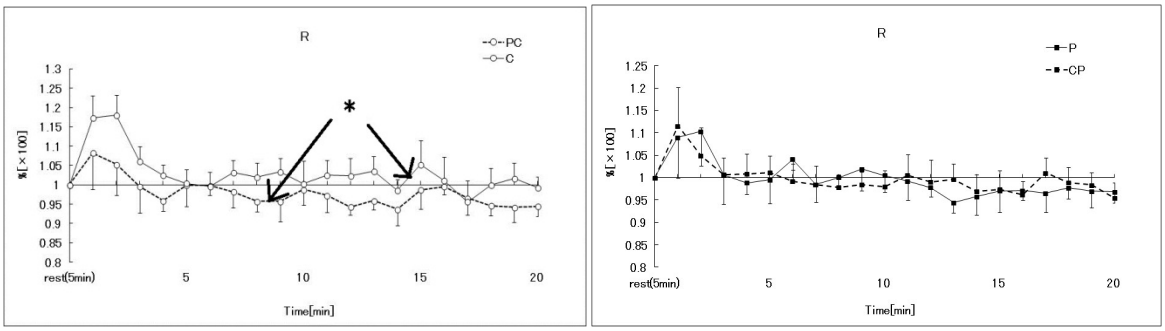

Fig. 6. Changes in respiratory quotient after soup intake, C and PC comparison. Data are means ± SD, two-way ANOVA (*: p <0.05). Fig. 7. Changes in respiratory quotient after soup intake, P and CP comparison after soup intake.

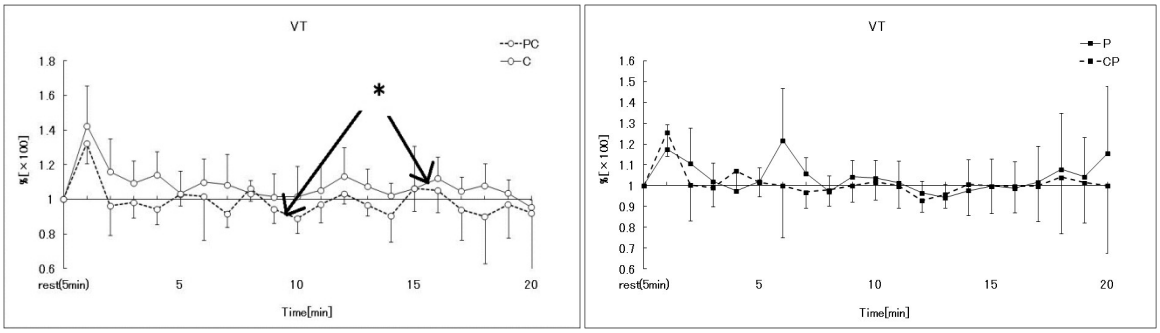

Fig. 8. Changes in VT: tidal volume after soup intake, C and PC comparison. Two-way ANOVA (*: p <0.05). Fig. 9. Changes in VT after soup intake, P and CP comparison.

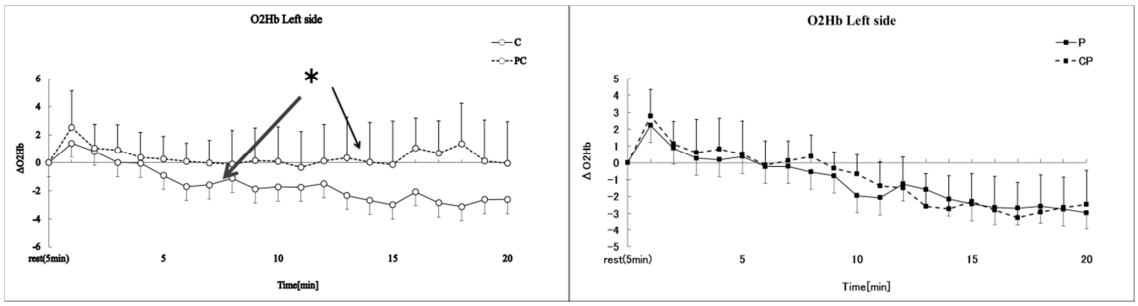

Fig. 10. Changes in O2Hb frontal left side after soup intake, C and PC comparison. Two-way ANOVA (*: p <0.05). Fig. 11. Changes in O2Hb frontal left side after soup intake, P and CP comparison.

3.3 Brain blood flow

Figures 10 and 11 show changes in the O2Hb concentrations in the frontal left side after soup ingestion. C decreased significantly compared to PC during the 20 minute recovery period ($p < 0.01$). However, there was no significant difference observed in the comparison between P vs. CP.

4. DISCUSSION

In our research, we studied the physiological effects of eating two nutritionally equivalent but differently flavored soups in different sequences. Depending on the sequence the soups were ingested, the subjects' sensory evaluations were rated as "pleasant" and "delicious." Moreover, the sequence P, CP was rated low in comparison to C. The subjects confirmed our belief that the palatability of C was high. With regard to the soup sequence, even if the sequence was changed, [C, PC and in between P, CP], there was no notable influence on subjects' rating of palatability. We think that the difference in the flavor ingredients invoked different physiological responses.

Next, we examined the physiological index. Because both soups were nutritionally equivalent we did not examine energy consumption. An increase in sympathetic nerve activity occurs when the heart rate increases, which happens when movement and stress start. Moreover, when the heart rate falls, the parasympathetic nerve rather than the sympathetic becomes dominant. In this experiment, a temporary increase in the heart rate immediately after ingestion was recorded for all the soups. A temporary fall of parasympathetic nerve activity was reported immediately after ingestion of the warm soup. Therefore, the rise of the heart rate immediately after ingestion was not based on a stress reaction, rather it was a general response when the soup was consumed, and we think that it was the result of the sympathetic nerve activity becoming temporarily predominant.

When the subjects consumed the delicious soup after the not delicious soup, the stress of drinking the latter soup carried over into the results of drinking the delicious soup (P). Regardless of the sequence in which the soups were consumed a significant change was not seen but subjects showed a higher stress value. This is thought to be due to the influence of stress from consuming the non-delicious soup first. However, when the soup was rated as delicious, stress was mitigated and the resulting fall in the heart rate could be due to the effect of parasympathetic nerve activity. For the respiratory quotient, the high value was intentionally shown to C. In between C and PC, a significant difference was not seen in between CP and P. The value higher than CP was shown. According to previous research [2], it has been reported that the consumption of palatable foods resulted in raised blood sugar levels, and the respiratory quotient also increased. Moreover, McGregor have shown that in rats mental stress results in the fall of the respiratory exchange ratio. In our research we conclude that the increase in the blood sugar levels is because the palatability of (C) was high. Conversely, the non C soup which was not rated highly for palatability resulted in heightened stress levels for the participants. This in turn led to a lowered respiratory exchange ratio for them [3]. For the tidal volume (VT) C was higher than CP, which is indicative of a deeper respiration for C. In addition, because the heart rate decreased we think that consumption of the C soup induced a sense of relaxation. For C the results of the heart rate and its relation to the respiratory quotient and VT suggest that the delicious soup creates a sense of relief and this relaxation effect causes an increase in the respiratory exchange ratio and a fall in the heart rate. On the other hand, when the sequence is P, PC with CP stress was felt and we think that this caused a fall in the respiratory quotient and an increase in the heart rate.

The influence of the delicious soup on its own and when it was consumed with the non-delicious soup was also examined. We examined the effects on the subject's metabolism (heart rate, respiratory exchange ratio and tidal

volume). However, the sequence effect of ingesting the delicious soup before the non-delicious soup was not investigated. A possibility that the soup sequence with a high flavor ingredient will affect metabolism was suggested.

The frontal cortex is called the cognitive domain and it is the location in the brain where likes and dislikes are evaluated. Other research has shown that there is a notable reaction in the left frontal cortex in response to a pleasant stimulus response [4]. Examining the influence of the sequence effect when C is compared to PC, we see that for soup C the O2hb concentrations decreased in comparison to PC, which maintained its initial level throughout the observation period. This suggests that the consumption of PC resulted in a pleasant reaction compared to C. The increase in the levels of oxygenated hemoglobin is a result of an increase in the blood flow, which in turn means an increase in brain activity. Conversely, when the non-delicious soup was consumed the level of oxygenated hemoglobin decreased.

It is interesting to note that the average level for PC is higher than the average levels for C, CP, and P. We believe by taking the non-palatable soup P first and the palatable soup C second, the sense of deliciousness was heightened. This can be seen in the rise in the levels of oxygenated hemoglobin in the latter half of the observation period. Thus, we think that the sequence PC yields the greatest physiological affect.

5. Conclusions

This research studied the physiological effects of eating two nutritionally equivalent but differently flavored soups (termed ‘rich’ and ‘weak’) in different sequences. Subjects’ taste impressions, cardiovascular respiration and frontal brain blood flow were evaluated. The order in which the soups were consumed was also examined. Comparisons were made between the consumption of ‘rich’ flavored soup only, and the consumption of ‘rich’ flavored soup after drinking ‘weak’ flavored soup first. It was found that such a sequence had a noticeable effect on the subjects’ heart rate, respiratory quotient, VT and frontal left side O2 hemoglobin. However, reverse comparisons between consuming the ‘weak’ flavored soup only, and the consumption ‘weak’ soup after drinking ‘rich’ flavored soup did not result in any noticeable effects. These findings suggest that the order of consumption of ‘rich’ flavored soup has a noticeable effect on human metabolism and cerebral blood flow.

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