The Influence of Thickeners of Food on the Particle size of Boluses

–A Consideration for Swallowing –

Running title: Thickness and particle sizes in boluses

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Abstract

Objective:

The purpose of this study was to examine the influence of thickeners with different levels of thickness on the sizes of particles in food boluses.

Background:

In medical and nursing care, thickeners are used to make food safe for patients with dysphagia. However, the effect of thickeners on the foods they are added to, especially during swallowing, is still unclear.

Methods:

The bolus particles of 20 healthy volunteers were photographed, and the digital images were used to estimate the sizes of particles in them. Eight test samples with thickeners with different levels of thickness were tested: six grades of thickened carrot juice with raw carrots in it, raw carrot with banana, and raw carrot alone. The particle homogeneity index (HI) and particle size index (SI) just before swallowing were calculated. The viscosities of the liquid part of the test samples were also measured.

Results:

The number of mastication cycles across the test samples was not significantly different. However, significant differences were found in SI and HI across the test samples: the absolute values of SI and HI tended to rise as the thickness of the test sample increased. The viscosity of the liquid part of the test sample also increased as the thickness increased.

Conclusion:

The differences in the thickness of food had an influence on the bolus particle sizes just before swallowing.

Keywords: Cohesiveness, Mastication, Particle size, Swallowing, Thickener

Main text:

Introduction

Mastication is an important function in humans [1] during which food particles are reduced in size, mixed with fluids from saliva and the food itself [2], and formed into a lubricated food bolus [3]. In medical and nursing care, for elderly persons with weakened abilities to chew, meals are often minced, as minced meals are considered easier to chew. However, the formation of unified food boluses that can be swallowed from the minced meals is difficult, and the boluses that are made are easily broken up [4]. Therefore, foods that are viscous, such as thickeners and starch, are added to make meals that elderly people can safely swallow.

It is now apparent that swallowing is triggered by certain threshold levels of lubrication, particle size, and/or plasticity of the food boluses [5]. Prinz & Lucas (1995) confirmed that food particles should have a diameter of 1.4 - 2.0 mm to achieve smooth deglutition [6]. However, persons with weakened abilities to chew might swallow food particles of inappropriate sizes [7, 8]. Therefore, to ensure that elderly persons eat safely, the size, volume, and properties of foods given to them have to be taken into account.

Furthermore, to provide food that is most suitable, the masticatory ability of each person needs to be objectively evaluated. Various methods have been used to evaluate the masticatory ability, among which laser diffraction is a representative method. Laser diffraction is suitable for the measurement of small particles but is unsuitable for measuring big particles. The sieve method is another method that can be used with natural food particles of any size. However, the particles need to be dry before sieving, and thus, this process takes time for the preparation of particles before measurement [3, 9]. Recently, Sugimoto et al. (2012), have developed a new method that uses a photographed digital image of the bolus particles to measure the particle size [10]. This method has the advantages of not requiring a drying process and of not being limited by the particle size. Therefore, this method is expected to be a simple and easy method that can be applied clinically.

It has been reported that the characteristics of food, such as its hardness, affect the particle size distribution [11], and that the characteristics of the food bolus, such as its rheological behaviour, contribute to the perceived ease of swallowing [3, 12]. Cohesiveness, and plasticity of the food bolus, as well as the particle size, and lubrication have been shown to be important for safe swallowing [5]. Furthermore, cohesiveness is suggested to be the most important factor because, to be swallowed easily, the bolus must behave as a single unit and not break up spontaneously [5]. It is also shown that the cohesiveness of the bolus is maximum just before swallowing [3, 13]. One commonly used method to improve the cohesiveness of the bolus in medical and nursing care is the application of a thickener. Hence, we thought that cohesiveness of the whole bolus could be improved by adding thickeners, which would increase the viscosity of foods, and might have an influence on the bolus particle size at swallowing and on the ease of swallowing. Banana, which has high cohesiveness [14], is sometimes used in medical and nursing care as a food that can be easily swallowed. However, the effect of the addition of thickeners and/or the combination of foods with different cohesiveness on the food bolus, especially during swallowing, is still unclear.

The purpose of this study was, therefore, to examine the influence of the thickeners or foods with high cohesiveness (banana) on the sizes of particles in the food boluses of healthy young adults as a pilot study before investigating the same in elderly subjects and patients with dysphagia. This might provide new information that should be considered when measuring the particle size. An additional aim of this study was to assess the influence of the thickeners on the sensory evaluation during swallowing because subjective sensory inputs are suggested to be involved in the initiation of swallowing [3].

Materials and methods

This study consists of the following three parts.

1) Experiment 1: Measuring the viscosity of the liquid part of the test food.

2) Experiment 2: The particle size of the bolus just before swallowing (masticating experiment).

3) Experiment 3: Sensory evaluation for swallowing.

Experiment 1: Measuring the viscosity of the liquid part of the test food

The viscosities of the carrot juice with varying densities of thickener, which was used as liquid part of the test food for the particle size experiment, were measured. Six degrees of thickened carrot juice (T0 - T5) were prepared using the thickener for dysphagia diets (TROMERIN® V, SANWA KAGAKU KENKYUUSHO, Co. Ltd., Tokyo, Japan) and carrot juice (squeezed vegetable juice - 100% vegetable, KAGOME, Co. Ltd., Tokyo, Japan). The upper part of Figure 1 shows the components of the thickened carrot juice. All the samples were prepared within 30 minutes before the measurement to avoid the changes in the fluidity of the thickened juice that might occur with time. Sine-wave vibro viscometers (SV-1, SV-100, A&D, Co. Ltd., Tokyo, Japan) were used to measure the viscosities. Into the test container, 10 ml of the sample was poured such that each container had a sample with a different degree of thickness. The temperature was raised from 20 °C to 40 °C, and the values of the viscosity at 37 °C (around body temperature) were selected for evaluation. Each sample was measured five times. A hot plate stirrer

(SRS311HA, ADVANTEC, Co. Ltd., Tokyo, Japan) was used to control the temperature [15].

Experiment 2: The particle size of the bolus just before swallowing (masticating experiment)

The effect of the thickeners with different levels of thickness or foods with high cohesiveness (banana) on the sizes of particles in the food boluses just before swallowing was investigated.

Subjects

Twenty healthy subjects, ten men and ten women, between 23 and 37 years of age with a mean age ± standard deviation of 26.7 ± 2.2 years, were chosen. None of the subjects had abnormalities in stomatognathic function, or the signs or symptoms of any neurological disorder. The purpose of the study was explained to the subjects, and informed consent was obtained from each subject.

The subjects were instructed not to eat any food, except water, for at least three hours before the experiment. All subjects followed this instruction. When asked, none of them reported a sensation of hunger at the beginning of the experiment.

This study, including experiment 3, was approved by the local ethics committee of Nagasaki University (approval number: 12052816-3) and was carried out in accordance with the guidelines of the

Declaration of Helsinki.

Test samples

Raw carrot, banana, and thickened carrot juice were used as test foods. A total of eight different test conditions were prepared for the masticating experiment. They are given in the lower part of Fig.1. Eight test containers were taken, each with two pieces of raw carrot (2 g in total). Three millilitres of thickened carrot juice were poured into the Six containers for C0-C5 such that each container had thickened carrot juice with a different degree of thickness (T0-T5). Thickened carrot juice was not poured into the containers for C&B and C. Raw carrot (2 g) (C), and raw carrot (2 g) with banana (3 g) (C&B) were also used as test samples (i.e., a total of eight conditions of the test samples [C0-C5, C, C&B] were used).

The volumes of the test samples were determined using the method used by Chen and Lolivret [12]. The error range in the weights of carrot, banana, and thickened carrot juice were adjusted to be within ± 0.05 g. The shapes of the carrot and banana were kept constant. Cylindric tablets of carrot or banana with a diameter of 25 mm and a height of 6 mm were made. These tablets were, then, cut in to four quarters. Hence, each piece was 6-mm thick, quarter round, and had a diameter of 25 mm. Two quarters (2 g in total) were used in a sample.

Determination of the number of mastication cycles

To ensure familiarity with the experimental condition and the end of the mastication sequence (the point of swallowing), a training session using two samples (C3, and C&B) was carried out at the beginning of the experiment. The subjects used a plastic spoon to place the test sample into their mouths. They were instructed to masticate the test sample and swallow it naturally. After the training session, the test samples of the eight test conditions were masticated. Two trials for each condition, that is, a total of sixteen test samples were masticated and swallowed naturally in a random order. The number of mastication cycles was counted by the experimenter by observing the jaw movements of the subjects. The subjects were not informed that the cycles were being counted to avoid disturbing the natural mastication-swallowing process. The average number of mastication cycles was calculated for each test sample condition. These average numbers were used for the particle size analysis.

Particle size analysis

The subjects were instructed to masticate the test sample by using the averaged cycle numbers for each condition mentioned above without swallowing. After mastication, the subjects spit out the food boluses into plastic cups. One trial was performed per test sample in a random order. The subjects rinsed their mouths with water between trials. The weights of the collected food boluses were measured. The change in the weight of the test sample after mastication was then calculated.

Particle size analysis was carried out as given in a previous report [10]. Each food bolus that was collected was mixed well so that the particles of carrot dispersed uniformly into the liquid components. One gram of it was picked out with a spoon and processed using two kinds of surfactants. The anionic surfactant, 0.032% fatty acid alkanolamide, was used first. The samples were, then, washed with water in a stainless-steel sieve with a 0.2-mm mesh. The processed particles were retrieved and dispersed in a plastic Petri dish with 0.06% benzalkonium chloride, the cationic surfactant. Dark field digital images of the processed samples were obtained using double dark field illumination. These digital images were, then, binarized using an image analysis software based on the method reported by Sugimoto et al. [10].

The regression process for the particle size and the ranked number of food particles are briefly described as follows. The food particle sizes (particle area) were plotted along the y-axis, and the particle numbers ranked according the particle area were plotted along the x-axis. A regression line was used to analyse the particle size distribution, and the relationship between the particle size and the particle number ranked according the particle area was, then, calculated [10]. Quadratic regression was used to ascertain the relationship between the number of particles and the size of particles greater than 2 mm in length. Linear regression for the natural logarithm of size was, then, obtained. The inclination of the regression line shows the particle homogeneity index (HI), and the y-axis intercept shows the particle size index (SI) [10]. A low absolute value of HI (gentle inclination) represented more homogeneity, and a low value of SI represented that the particle size of the largest particle had become smaller. Regarding C&B, the particle sizes were analysed on two types of C&B foods to avoid the effect of the particles of banana (details are mentioned in the Discussion): one with particles of banana (C&B+), and the other after removing as many particles of banana as possible (C&B-).

Experiment 3: Sensory evaluation for swallowing

Subjects

Twelve healthy subjects, eleven men and one woman, between 24 and 35 years of age with a mean age ± standard deviation (SD) of 29.3 ± 4.1 years were included in this experiment. None of them had abnormalities in stomatognathic function, or the signs or symptoms of any neurological disorder. The purpose of the study was explained to the subjects, and an informed consent was obtained from each subject. The group who participated in the sensory evaluation was not the same group that participated in the particle size analysis.

Test samples

Four conditions of the test samples were used: C0, C1, C3, and C5 as mentioned in experiment 2. Since the sample numbers for particle size analysis (eight conditions) was too many for sensory evaluation, we adopted four conditions for this experiment to avoid the influence of satiety of the subjects on swallowing.

Sensory evaluation of the ease of swallowing

At the beginning of experiment 3, training sessions were carried out using C3 and C5, once for each condition. The subjects were instructed to masticate and swallow the test sample naturally. The subjects evaluated the 'ease of swallowing' immediately after each trial using scores between 1 and 5, where '1' indicated that the sample was 'difficult to swallow', and '5' indicated that it was 'easy to swallow'. In the training session, they were asked to estimate the ease of swallowing the test sample with reference to C3, which was assigned a score of '3'. It was used as the basis for later evaluations. The subjects rinsed their mouths between trials. After the training, evaluations of the four test samples were performed in a random order - three times for each condition.

Statistical analysis

The parametric distribution of data was analysed using the Kolmogorov-Smirnov test. As the HI did not show normality, a nonparametric test was used to analyse it. Parametric tests were also carried out for the other parameters: viscosity, number of mastication cycles, change in the weight of the test sample, SI, and sensory evaluation of swallowing. The one-way ANOVA test was performed on the viscosity, the change in the weight of the test sample, and the SI. Post hoc comparisons were made using the Tukey test. The test sample condition was the factor analysed in the one-way ANOVA (six levels for viscosity: T0-T5; eight levels for weight change: C0-C5, C&B, and C; nine levels for SI: C0-C5, C&B+, C&B-, and C). The two-way ANOVA test was performed on the number of mastication cycles and the sensory evaluation of swallowing. The data were used without averaging for these tests (two trials for the number of mastication cycles; three trials for the sensory evaluation). The factors analysed in the two-way ANOVA were ‘subject’ (20 subjects for the mastication cycles; 12 subjects for the sensory evaluation) and the ‘test sample condition’ (eight levels for the number of mastication cycles: C0-C5, C&B, and C; four levels for the sensory evaluation: C0, C1, C3, and C5). Post hoc comparisons were made using the Tukey test. On HI, the Kruskal-Wallis test was performed, followed by the Dunn method for multiple comparisons. Version 21 of SPSS (IBM®) was used for statistical analysis. $P<0.05$ was considered to be significant.

Results

Experiment 1: Viscosity of the liquid part of the test food

The level of thickness of the thickener ($p<0.001$) was found to be a significant factor on the ANOVA test for analysing the viscosity. As the thickness level of the thickener rose, the viscosity became higher (Fig. 2).

Experiment 2: The particle size of the bolus just before swallowing (masticating experiment)

The results of the ANOVA test for the number of mastication cycles showed that the factors of the test condition ($p<0.001$) and subject ($p<0.001$) were significant. However, the interaction between the condition and the subject was not significant ($p=0.198$). Post hoc test showed that the number of mastication cycles in condition C was significantly higher than that in other conditions ($p<0.05$) except C2 ($p=0.123$). The difference between C0-C5 and C&B were not significant ($p=1.00$). The mean numbers of mastication cycles (mean ± SD) were 31.3 ± 11.5 for C0, 32.1 ± 11.8 for C1, 33.0 ± 11.7 for C2, 31.6 ± 11.8 for C3, 32.5 ± 11.7 for C4, 32.7 ± 11.3 for C5, 32.3 ± 10.5 for C&B, and 35.9 ± 10.1 for C. The range of the coefficient of variation (CV) was between 0.28 and 0.37 for the test conditions, with a mean CV of 0.35. The range of the mean numbers of mastication cycles (mean ± SD) was between 18.4 ± 4.0 and 54.8 ± 7.3 cycles for the subjects. The range of the CV between the subjects was from 0.11 to 0.20 with a mean CV of 0.14. The mean number of mastication cycles showed a larger variation between the subjects with a relatively smaller CV within each subject, resulting in larger standard deviations (SDs) for each condition.

The weight of each test sample increased after mastication. The differences in the change in weight after mastication were significantly different across the foods tested (Fig. 3). The increase in the weight was significantly lower in C1 and C2 than in C&B ($p<0.05$) (Fig. 3).

The SI was significantly different between the test samples. C&B- and C&B+ showed significantly higher SI values than did C0 and C1 ($p<0.05$). C5 showed a significantly higher SI value than did C0 ($p<0.05$). C showed a significantly lower SI value than did C&B- and C&B+ ($p<0.01$) (Fig. 4).

The HI was also significantly affected by the test sample condition. C4, C5, C&B-, and C&B+

showed significantly higher HI values than did C0, C1, and C ($P<0.05$). C showed a significantly lower HI value than did all the other test samples (Fig. 5).

Experiment 3: Sensory evaluation of swallowing

In the ANOVA results for the ease of swallowing, the test condition ($p<0.001$), subject ($p<0.001$), and their interaction (condition × subject) ($p=0.001$) were all significant factors. The results of the sensory evaluation by condition showed different patterns depending on the subject because of significant interactions. However, the post hoc test on the condition showed that the ease of swallowing in C3 ($p<0.001$) and C5 ($p<0.001$) were significantly higher than that in C0. There was no significant difference between C0 and C1 ($p=0.085$) (Fig. 6).

Discussion

The SI and HI tended to become higher as the thickness of the test sample increased (Fig. 4, and 5). These findings may indicate that when a thickener surrounds the food, the food boluses are formed with particles that are bigger and more heterogeneous in size.

Methodological considerations (limitations)

1. Method for particle size measurement

The method [10] used in this study can perform the particle size analysis without a drying process and does not take much time for preparation before the measurement. Moreover, this method is not limited to the estimation of particle size. Simplification of the particle size and distribution by using HI and SI in combination can easily express the bolus condition with regard to the particle. However, the quantity that is measured is limited because it is necessary to disperse the particles such that they do not overlap each other when placed on a Petri dish. Therefore, only 1 g from the whole food bolus was used for particle size analysis in the present study. Although the small test portion is not accurately representative of the whole food bolus, we believe that by mixing it well so that it becomes uniform this limitation was reduced in this study.

2. The effect of spitting out the bolus

In the present study, the particles were measured using food boluses that had been spit out by subjects with no neurological or stomatognathic disorders. A report showed that spitting the food bolus out did not modify the mastication behaviour [16]. However, during the natural mastication of solid food, a portion of the food bolus reaches the oropharynx [14, 17]. The processing, transport, and bolus formation of food can also be modified by the consciousness of the subject [18]. Therefore, differences might be present between the conditions of the food boluses formed by natural mastication and those formed in the experimental situation used in the present study. However, at present, it is technically impossible to measure the particle size without spitting the boluses out. Hence, when interpreting the findings of this study, it was kept in mind that the food boluses collected in this study were not the same as naturally swallowed boluses, but only close approximations [11].

In order to reduce the differences between the food boluses formed during natural swallowing and those formed under experimental conditions, the natural mastication-swallowing process was observed at the beginning of the present study to count the number of mastication cycles for each test sample. The subjects were instructed to chew the test sample as naturally as possible before spitting the boluses out. The numbers of mastication cycles, which were counted in the natural mastication-swallowing process, were used to analyse the particle size.

3. Solid/liquid ratio

The ratio of the solid to the liquid, which was the ratio between the carrot and the thickened juice in this study (solid/liquid ratio), could have influenced the results even if all the samples were constituted with the same level of thickener because of the differences in the swallowing modalities between solid and liquid foods [17]. Only one level of solid/liquid ratio (solid/liquid, 2 g:3 mL) was used in this study. The ratio between the carrot and the banana, although it is a solid to solid ratio, could have also influenced the results of this study because carrot is a low cohesive food, whereas banana is a high cohesive food. The difference in the taste between the carrot and banana could have also influence the results of this study. These issues need to be addressed in future investigations.

The effect of the thickness and number of mastication cycles on the particle size

As the particle size distribution in the food boluses is reported to be one of the key parameters contributing to swallowing (1, 8), it is important to know the particle size to ensure safe swallowing. The present study provided new information that thickeners influence the particle size distribution within the bolus and the ease of swallowing, but had little influence on the particle size (SI). This could be due to the smoothness and the increased cohesiveness of the bolus caused by adding a thickener. In this study, in addition to the thickener used, banana, a food with high cohesiveness, was also found to influence the particle size distribution [9]. C&B+ showed the highest SI values, followed by C&B- (Fig. 4). Large particles of banana were observed in the C&B+ test sample. These particles were thought to cause the particle sizes of carrot in C&B+ to increase more than those in other test samples, thereby, influencing the present results. Therefore, in C&B-, as many particles of banana as possible were removed. Nevertheless, higher values of SI and HI were still seen in C&B- when compared with C0 and C1. Moreover, some particles of carrot in C&B- were still found to be surrounded by particles of banana. This was thought to cause the surfaces of the particles of carrot to become smooth and the cohesiveness of the food boluses to increase. The particles may have, then, changed into forms that were easier to swallow resulting in the higher values of SI and HI seen in C&B-.

The number of mastication cycles seen before the food is swallowed has been reported to depend on the volume and characteristics, such as water content, fat percentage, and hardness, of the food being masticated [19]. A previous study, reported a significant reduction in the number of chewing cycles observed when masticating butter-coated toast as compared with masticating non-coated toast [19]. The authors of that study suggested that the butter enhanced the lubrication and bolus formation of dry food, thus reducing the number of chewing cycles needed before swallowing.

In our study, the number of mastication cycles was significantly different between the subjects. Similar findings have been reported in earlier studies [8, 16, 20]. This must have caused the large SDs of the mastication cycles for each thickener condition used in the present study. However, the SDs of the mastication cycles for each subject showed relatively constant numbers of mastication cycles. Therefore, the following findings need to be considered carefully. In the present study, the number of mastication cycles observed did not significantly differ with changes in the thickness of the thickener around the carrot, except in the sample that used carrots alone. This might be because although carrot contains a large amount of water, it is a relatively hard food. A certain number of mastication cycles might be needed to form food boluses that are safe to swallow. The particle size distributions observed between the different test samples used in the present study were significantly different despite there being no significant difference in the number of mastication cycles. This might have been because food particles with thickened juice are difficult to chew and break down into small pieces as they tend to slip between the teeth [4]. The two-way competition model for occupying a restricted space between the upper and lower teeth [21] may additionally explain the larger particle sizes in the thicker conditions. Due to the higher viscosity of the thickened juice, the piling of the small particles compensates for the size of the large particles, and the small particles occupy part of the breakage sites of the large particles [21] resulting in a decreased overall rate of breakage of food. In addition, thickeners may mask the ability of the mouth to classify particles by reducing the sensitivity of the oral cavity to them. This may lead to the persistence of large and heterogenous particles. Thickeners may also improve the lubricative property of the food bolus making it possible to swallow such particles.

Change in the weight of the food boluses after mastication

Swallowing can be explained using the three-stage model of swallowing, the stages of which are the oral, pharyngeal, and oesophageal stages. However, the limits of each stage are difficult to define in this model. Another model, called the process model, has been proposed [17]. According to this model, the masticated food is sent into the oropharynx, and the epiglottic valleculae through the fauces. It accumulates there by the movement of the tongue before being swallowed (stage II transport). The leading edge of the food often enters the hypopharynx before being swallowed [17,22]. In this study, the subjects were instructed to hold food in their mouth consciously. This situation differs from feeding in daily life.

The weight of the food boluses changed after mastication. In C1 and C2, the increase in the weight of the boluses was smaller when compared with those of other test samples (Fig. 3), and the number of subjects whose boluses decreased in weight was more. This decrease might be because the liquid component in C1 and C2 might have entered the oropharynx earlier by gravity making it impossible to spit that part of the food out. However, the weight of C0 increased more than those of C1 and C2, the reason for which is unclear.

The weight of the food boluses increased in all subjects except in one subject in C3, C4, and C5, and two subjects in C&B. As the thickness of the food increased, the weight of the food bolus increased (Fig. 3). C&B showed the highest increase in weight. With increasing viscosity, the dispersion of the bolus might have decreased. This might have made it easier to hold the bolus in the mouth, making it possible to spit out higher quantities of food. In addition, at higher levels of thickness, higher quantities of saliva might have been secreted. The sweetness of the banana might have also contributed to the increase in the secretion of saliva. These factors may have contributed to the increase in the weight of C&B.

The viscosity of the thickener

The viscosity of the thickened juice increased as the levels of thickener used increased. Generally, 1 to 2 g of the thickener, which is used to prepare dysphagia diets, is mixed in 100 ml of liquid in the clinical setting. This is equivalent to the conditions in T1 and T2. In these conditions, the particle sizes in the food when the thickener was added were not significantly different from those when no thickener was added (C0). These findings suggest that, in addition to not changing the particle size significantly, a thin thickener level does not effectively make food particles (solid part of the food) suitable for safe swallowing. However, the addition of even thin levels of thickener can improve the safety of swallowing the liquid part of the food by thickening the leading component of the mixed food and by preventing its early entry into the hypopharynx before swallowing.

On the other hand, in the thicker conditions, the results of our sensory evaluation for swallowing were significantly different with different thickener conditions: as the thickness of the thickener juice increased, the ease of swallowing also increased. Thus, thickened juice may increase the ease of swallowing. However, it may not always be true that the risk of aspiration can be decreased by increasing the thickener level, because the increased thickener level could lead to the subject using excessive force while swallowing (12). Moreover, the results of our sensory evaluation for swallowing based on the test condition showed different patterns depending on the subjects. The subjective sense of swallowing for young healthy individuals could be different from that of older subjects or patients with dysphagia. Thus, the suitable thickness level of the thickener should be considered according to the oral functions of individuals.

Clinical significance

In the present study, it was demonstrated that thick and viscous foods, such as banana, around solid foods, such as carrot, influenced the particle size distribution of the food boluses before swallowing by making the particle sizes bigger and more heterogeneous. The findings of this study suggest that the addition of a thickener might help the formation of the food bolus by increasing its viscosity. It also suggests that when measuring the particle size and interpreting the results, we should consider the thickness of the thickener added to the food. Future studies in older people or patients with dysphagia are necessary for the direct applicability of the results.

Conclusion

In the present study, it was suggested that thickeners may influence the particle sizes in the food bolus during swallowing, and that as the level of thickness increased, the particles became bigger and more heterogeneous in size. However, it was still necessary to consider the influences of the number of mastication cycles, the change in weight and solid/liquid ratio of food (e.g., presence or absence of liquid). Moreover, we also have to pay attention to the difference between "during swallowing" and "just before swallowing" when we interpret the present findings.

Viscous foods, such as banana, were also suggested to affect the particle sizes. These findings suggest that the increased viscosity of thickeners and banana could help patients swallow boluses with bigger and more heterogeneous particles. Moreover, the present findings provide new information that when using methods to analyse the particle size, the thickness level of the food should be considered.

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Fig. 1 The components of the thickened carrot juice (the liquid part of the test sample) and the test food. The upper part of the figure shows the components of the thickened carrot juice used for measuring viscosity of the thickened carrot juice. The lower part shows the components of the test samples used for the masticating experiment. C: carrot; C&B: carrot and banana

Fig. 2 The change in viscosity according to the thickener level (mean ± SD)

Fig. 3 The change in the weight of the test sample after mastication (mean ± SD)

Fig. 4 The particle size index (SI) under each test sample condition (mean ± SD)

Fig. 5 The particle homogeneity index (HI) under each test sample condition. The centre lines show the medians; the box limits indicate the 25th and 75th percentiles; and the whiskers indicate the minimum and maximum values

Fig. 6 The degree of ease of swallowing (mean ± SD)

Components of the thickened carrot juice (liquid part of test food)

Thickened juice conditions	T0	T1	T2	T3	T4	T5
Carrot juice (ml)	20	20	20	20	20	20
Thickener (g)	0	0.3	0.6	0.9	1.2	1.5

Components of test food

Test food conditions	C0	C1	C2	C3	C4	C5	C&B	C
Thickened carrot juice (ml)	3	3	3	3	3	3		
Raw carrot (g)	2	2	2	2	2	2	2	2
Banana (g)							3	

Fig.1

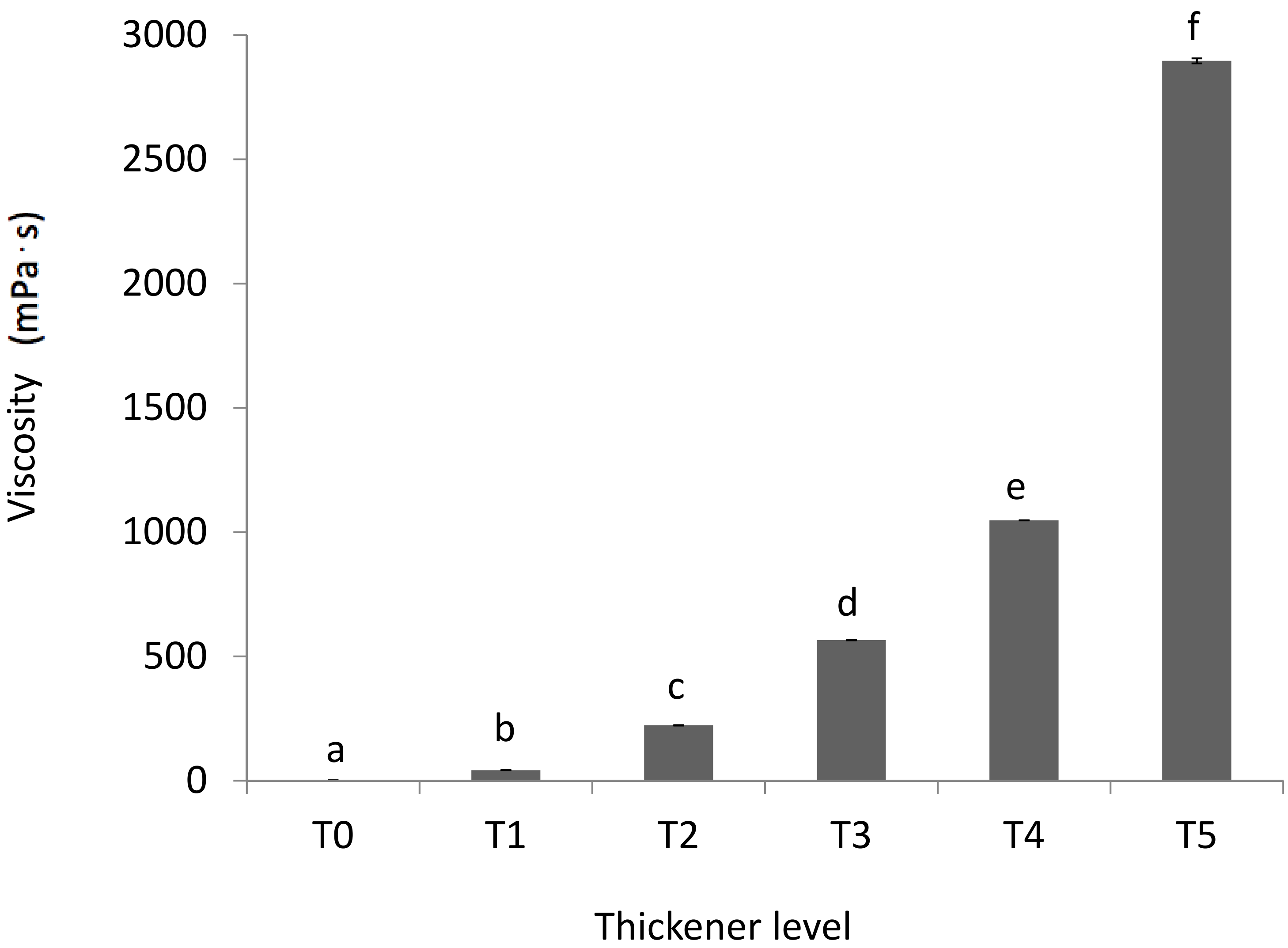

3000
2500
2000
1500
1000
500
0
Viscosity (mPa·s)
a
b
c
d
e
f
T0
T1
T2
T3
T4
T5
Thickener level

Fig.2

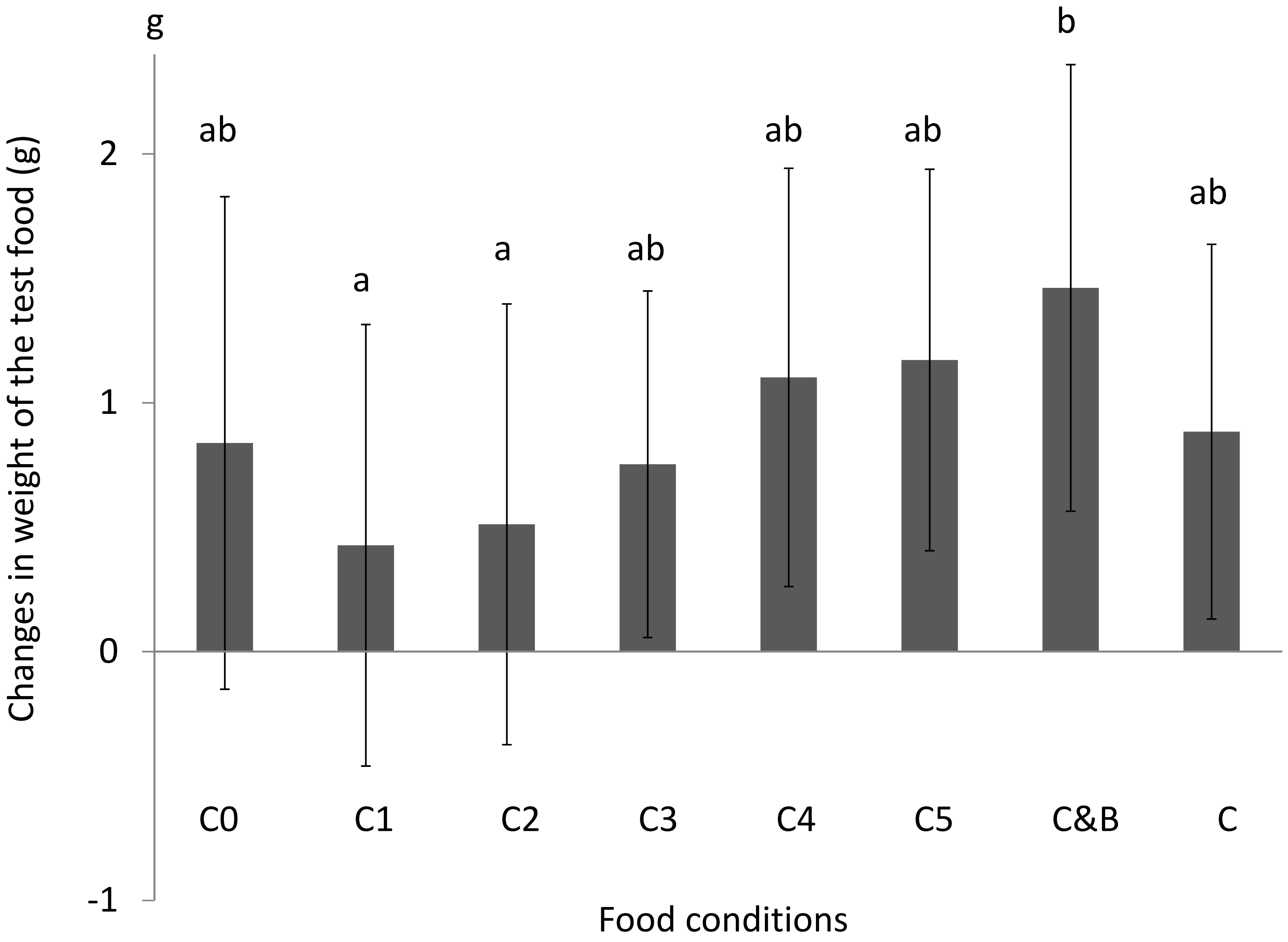
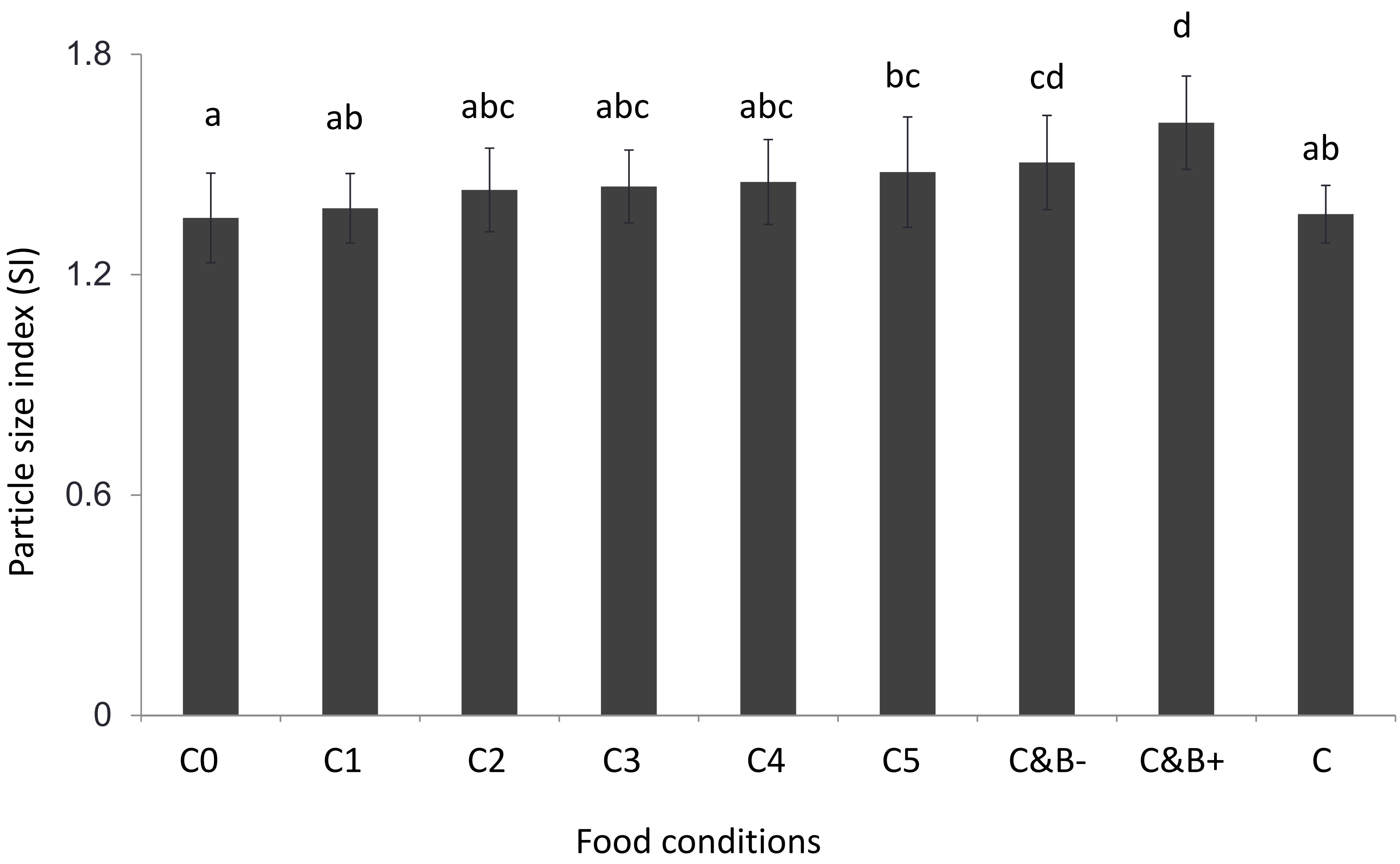

g
Changes in weight of the test food (g)
2
1
0
-1
ab
a
a
ab
ab
ab
b
ab
C0
C1
C2
C3
C4
C5
C&B
C
Food conditions

Fig.3



Particle size index (SI)
1.8
1.2
0.6
0
a
ab
abc
abc
abc
bc
cd
d
ab
C0
C1
C2
C3
C4
C5
C&B-
C&B+
C
Food conditions

Fig.4

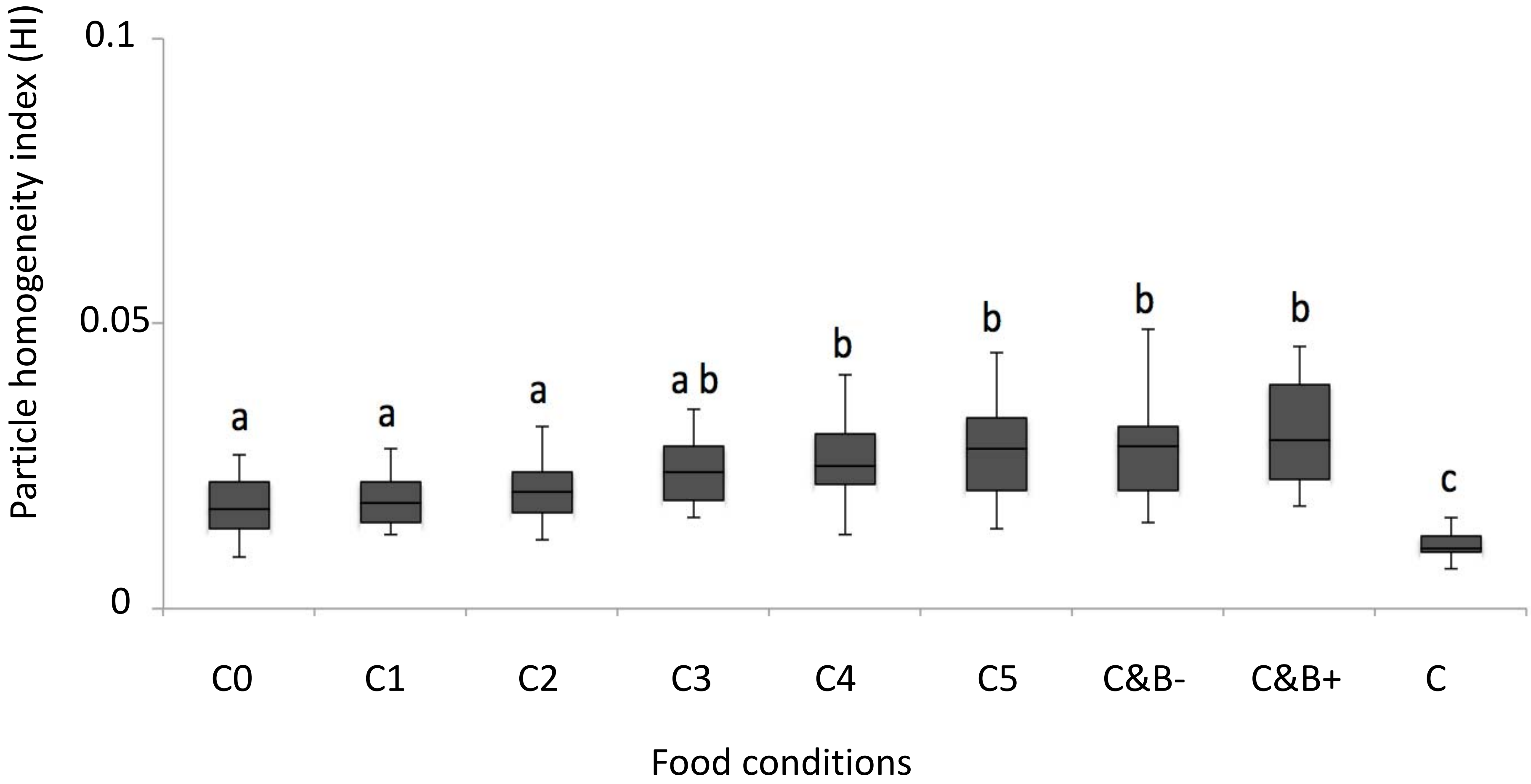

Particle homogeneity index (HI)
0.1
0.05
0
a
a
a
a b
b
b
b
b
c
C0
C1
C2
C3
C4
C5
C&B-
C&B+
C
Food conditions

Fig.5

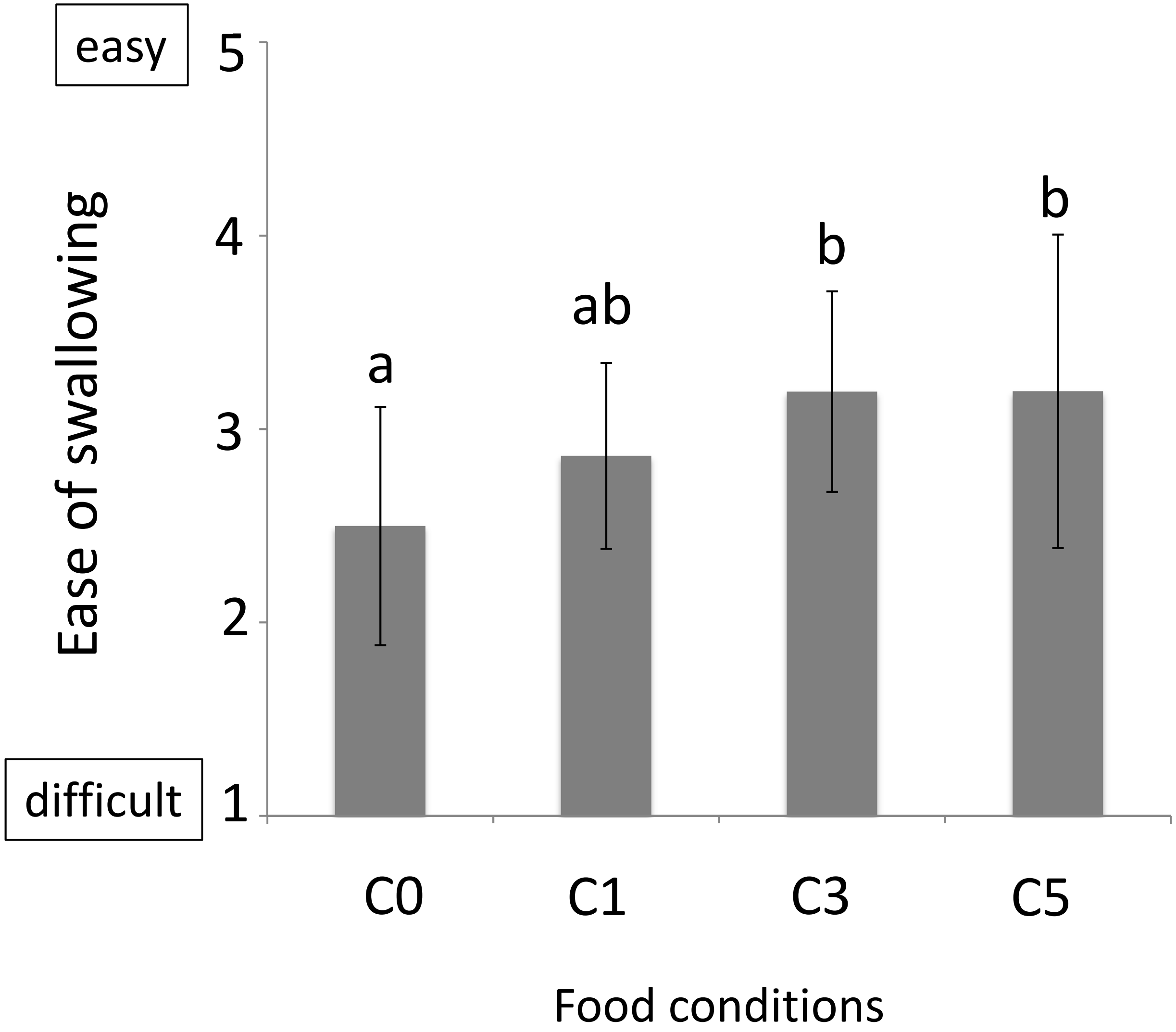

easy
difficult
Ease of swallowing
5
4
3
2
1
a
ab
b
b
C0
C1
C3
C5
Food conditions

Fig. 6