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EFFECT OF FLAVOUR ENHANCERS ON THE OCCURRENCE OF SENSORY-SPECIFIC SATIETY IN HUMANS DEPENDING ON THEIR SEX AND AGE

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The study was aimed at determining the effect of flavour enhancers on the occurrence of sensory-specific satiety (SSS) phenomenon in young and elderly people of both sexes. Investigations involved a group of 60 subjects (30 young and 30 elderly ones, 15 women and men in each group) who rated the pleasantness of instant products with various sensory properties (pasta with Bolognese sauce, lemon gelatin dessert, fruit semolina) before and after *ad libitum* consumption of pasta with Bolognese sauce without and with the addition of flavour enhancers (sodium monoglutamate, sodium inosinate and a mixture of sodium inosinate and sodium guanylate). A significant effect ($p<0.001$) of age on the development of SSS was demonstrated in the study, yet only in the case of young people. The addition of flavour enhancers to pasta with Bolognese sauce intensified the occurrence of sensory-specific satiety, however that effect appeared to depend on the sex of the examined and was distinctly higher in women than in men. It was also demonstrated that in the elderly the feeling of satiety occurred at a relatively lower intake of pasta with Bolognese sauce as compared to the young people and the addition of flavour enhancers had no significant effect on the content of energy ingested with a meal in both sex groups.

INTRODUCTION

Apart from satiety, which is a sensation limiting the intake and prompting to cease consumption completely, there exists the phenomenon of sensory-specific satiety (SSS) that is responsible for adding qualitative variety to a diet. The SSS is defined as a decline, progressing in the course of eating, in pleasure felt as a result of reacting to sensory properties of currently consumed food, with a concomitant lack of changes or an increased interest in food with different sensory properties [O'Doherty *et al.*, 2000]. The generation of the SSS does not result from the stretching of stomach nor metabolic or thermal factors that determine the occurrence of the sensation of satiety. That sensation is developing as a successive weakening of the response of brain neurons susceptible to sensory stimuli originating from the ingested food, due to which in the course of eating its taste, aroma and other sensory properties are becoming less pleasant for a consumer. Simultaneously, the susceptibility of neurons responsible for the reception of diverse sensory signals remains unchanged, whereas food with different sensory properties is perceived as more attractive than that which was consumed previously [Rolls, 2005]. A change in the hedonic evaluation of sensory stimuli generated by the food ingested has a considerable effect on the course of consumption (size and composition of a meal) [Rolls & de Waal, 1985]. In research works addressing that phenomenon, the SSS is measured as a decrease in pleasantness of food consumed *ad libitum*, which is manifested several minutes after beginning of meal consumption and may span for even a couple of hours.

It is common knowledge that the amount of food consumed within one meal is linked with feeling satiety which is of significance to the maintaining of energy balance [Raynor & Epstein, 2001]. The type of satiety discussed usually is not a sufficient reason to finish a meal once it is composed of sensorically-diversified food products. Hetherington [1996] demonstrated that people who finished their meal due to satiety and were offered food different in terms of sensory properties, ate it overcoming the already reached state of satiety. Rolls *et al.* [1981] were either insufficient in reaching, under experimental conditions, the state in which the subjects would be so satiated that they would not display any positive response to food with definitely diverse palatability, although the authors do not exclude that such a state is possible to reach.

Studies carried out so far into the sensory-specific satiety have indicated that it might be determined by a variety of nutritional factors linked with food, including: monotony of a diet [Rolls & de Waal, 1985], protein content [Gendall *et al.*, 1999; Vandewater & Vickers, 1996], fat content [Rolls *et al.*, 1999b; Snoek *et al.*, 2004] and dietary fibre content [Johnson & Vickers, 1991] of a meal, time of chewing [Rolls & Rolls, 1997], colour [Rolls *et al.*, 1982], aroma [O'Doherty *et al.*, 2000], texture [Guinard & Brun, 1998] and volume of a meal [Bell *et al.*, 2003] as well as sweetness [Vickers *et al.*, 1998] and type of a sweetener applied [Galiński & Gawęcki, 2000].

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Dietary stimulation and its impact on human behaviour depend not only on stimuli generated by food ingested but also on the capacity for their reception. Results of some studies proved that women have usually lower recognition thresholds of basic tastes as compared to men [Okoro *et al.*, 1998; Sato *et al.*, 2002] and demonstrated a higher reactivity to electric stimulation of a tongue [Coats, 1974], which can be of significance to the SSS sensation.

A number of research papers [Mowe & Bohmer, 1996; Murphy, 1993; Rolls, 1993, 1999a; Rolls & McDermott, 1991; Schiffman, 1993, 1994; Wysocki & Pelchat, 1993] have emphasized that in the elderly the sensitivity to taste and smell is subject to deterioration. Rolls [1994] demonstrated that deterioration of the functions of chemosensory senses, progressing with age, is likely to be the reason of the disappearance of sensory-specific satiety, appetite depletion and more monotonous diet.

To prevent unfavourable changes in nutritional behaviours in the case of consumers with an impaired capacity for feeling sensory-specific satiety, the application of flavour enhancers might proved helpful. They are substances that, while having no perceptible flavour, are capable of intensifying the sensation of taste generated by other food ingredients. They are applied to increase palatability of food in a number of the food industry branches, especially in the production of ready-to-eat and easy-to-prepare food (mainly of "instant" type). The most commonly applied flavour enhancers include: monosodium glutamate (MSG) as well as sodium and calcium salts of inosinic acid (5'IMP) and guanylic acid (5'GMP) [Komorowska *et al.*, 2002]. Little is known, however, on the mechanisms of enhancers action on flavour receptors, their role in improving palatability of dishes and their effect on the intake of food.

The available references provide scarce reports attempting to elucidate the effect of flavour enhancers on the regulation of food intake, hence the reported study was aimed at determining the impact of flavour enhancers on the occurrence of sensory-specific satiety in humans as affected by their sex and age.

MATERIAL AND METHODS

The study involved 60 women and men, including 30 young subjects at the age of *ca*. 20 years and 30 older people at the age of *ca*. 70 (Table 1). The group of young subjects was constituted by students of the Agricultural University of Poznań, whereas that of the elderly subjects – by members of the III Age University and Seniors Club "Urok Jesieni" in Poznań. All participants of the study had normal body mass (20 kg/m^2<BMI<25 kg/m^2), were non-smokers, did not take any medicines impairing taste-aroma perception [Gawęcki, 1994; Schiffman & Zervakis, 2002] and did not declare aversion to any of the products tested.

TABLE 1. Characteristics of the group examined (mean ±SD).

Subjects examined		n	Age (years)	Body mass (kg)	Height (m)	BMI (kg/m^2)
Young	Women	15	20.5±1.1	58.9±5.7	1.65±0.04	21.6±1.8
	Men	15	21.1±1.2	71.9±8.8	1.79±0.05	22.3±1.7
Elderly	Women	15	68.9±6.3	61.5±5.9	1.62±0.04	23.5±1.6
	Men	15	70.4±6.5	69.8±6.0	1.70±0.06	24.1±1.1

n – the number of subjects examined

The phenomenon of sensory-specific satiety was investigated with the modified method described by Hetherington [1996], based on a specially constructed form. In subsequent sessions of studies, the participants evaluated the pleasantness of three test products differing distinctly in terms of flavour (initial score), then consumed a test meal, *i.e.* pasta with Bolognese sauce with or without flavour enhancers, until sated. Next, 2, 10, 30, 60 and 90 min after finishing the consumption of pasta, the subjects again received samples of the same products for evaluation. A measure of the SSS were differences in pleasantness scores recorded for a given product before and after taking the test meal.

Pleasantness rating was carried out for three instant food concentrates: pasta with Bolognese sauce, lemon gelatin dessert and fruit semolina, prepared for consumption directly before the experiment following producers' instructions. Recipes of the products were elaborated and prepared at the Poznań Department of Food Concentrates, Institute of Agricultural and Food Biotechnology in Warsaw. Pasta with Bolognese sauce was prepared in four versions – without and with the addition of flavour enhancers: monosodium glutamate (MSG), sodium inosinate (IMP) and a mixture (1:1) of sodium inosinate and sodium guanylate (IMP+GMP). Doses of flavour enhancers and table salt were adjusted so as to obtain a comparable level of perceptible salty taste in all versions (Table 2). The proximate chemical composition and energy value of the ready-to-eat test products were presented in Table 3. Temperature of the products served reached 55–58 °C. During evaluation each person received (in plastic cups) their 5-g samples and low-mineralized water "Żywiec Zdrój" for rising mouth. All subjects participated in four experimental sessions (with different versions of pasta with sauce consumed *ad libitum*), however one person par-

TABLE 2. Percentage of salts and flavour enhancers in particular versions of pasta with Bolognese sauce (after preparation for consumption).

Additives	Pasta with Bolognese sauce			
	without flavour enhancer	with MSG	with IMP	with IMP+GMP
Salt	1.075	0.825	1.050	1.050
MSG	-	0.250	-	-
IMP	-	-	0.025	-
IMP+GMP	-	-	-	0.025

TABLE 3. Energy value and proximate chemical composition of 100-g portions of test products (prepared for consumption).

Test product	Energy value (kcal)	Protein (g)	Fat (g)	Carbohydrates (g)	Water (g)	Ash (g)
Pasta with Bolognese sauce	93	3.15	0.99	17.73	76.65	1.48
Lemon gelatin dessert	53	0.10	0.00	13.15	86.73	0.02
Fruit semolina	98	2.90	0.30	20.96	75.47	0.37

ticipated in only one session a day. Time interval between subsequent sessions for the same person accounted for minimally 2 days. At the beginning of each session, the subjects – asked earlier to abstain from eating at least 3 h before its initiation – evaluated the level of their hunger (satiety) with the use of a 100-mm visual analogue scale, marked "very hungry" at the left end and "very satiated" at the right end. The same evaluation was carried out by the subjects after eating pasta with Bolognese sauce until sated (the portion consumed was noted down and used to evaluate the content of energy ingested with the meal). Pleasantness of particular test products before and after ingestions of pasta with Bolognese sauce was rated with the use of a 100-mm graphic scale, with margin markings "very unpleasant" and "very pleasant". The subjects had no access to previous ratings. Particular experimental series were recorded on separate sheets of paper, thus preventing a comparison of results and being influenced by them.

In the statistical analysis of results use was made of: Student's t-test for paired and unpaired samples, one-way and three-way analysis of variance in the system of repeated measurements, and analysis of correlation and regression [Stanisz, 1998]. All calculations were carried out with the use of STATISTICA PL ver. 7.1 software.

RESULTS AND DISCUSSION

Table 4 presents changes in ratings of the pleasantness of test products 2 min after *ad libitum* consumption of pasta with Bolognese sauce without and with the addition of flavour enhancers. As it results from the table, the intake of pasta with Bolognese sauce, irrespective of its version, evoked the sensory-specific satiety in young subjects and the observed declines in pleasantness ratings were statistically significant, except for girls consuming the pasta without the addition of flavour enhancers. In the group of elderly subjects, the sensory-specific satiety was evoked by the intake of pasta with sauce with the addition of monosodium glutamate and only in the group of men. In the other cases, that phenomenon was not observed and differences reported in pleasantness ratings of the pasta before and after its consumption were statistically insignificant. Amongst four variants of the pasta, immediately after *ad libitum* consumption by women, both the young and the elderly ones, the greatest decrease in pleasantness ratings was observed for the pasta with the addition of IMP. In the group of young men, the greatest decrease was noted in the case of pasta with sauce with the addition of MSG, whereas in the group of elderly men, 2 minutes after the consumption, the greatest changes in pleasantness scores were observed for dishes without the addition of flavour enhancers. In the case of the other products analyzed, only slight changes in pleasantness ratings were recorded (except for a significant increase in pleasantness score of lemon gelatin dessert after the consumption of the test meal with MSG by young women), which indicates that the satiety evoked was sensory specific.

In order to determine the significance of the effect of age, sex and type of enhancer applied on changes in pleasantness scores of pasta with Bolognese sauce 2 min after its *ad libitum* consumption, a three-way analysis of variance with repeated measurements was carried out in the study. Significant ($F=13.499$, $p<0.001$) appeared to be only the effect

TABLE 4. Changes in pleasantness scores (mean±SEM) for test products 2 minutes after *ad libitum* consumption of pasta with Bolognese sauce with and without the addition of flavour enhancers.

Test meal – pasta with Bolognese sauce	Sex	Units of measure#	Young subjects			Elderly subjects		
			Pasta with Bolognese sauce†	Lemon gelatine dessert	Fruit semolina	Pasta with Bolognese sauce†	Lemon gelatine dessert	Fruit semolina
Without the addition of flavour enhancer	Women	mm	-10±6^{a}	0±4^{a}	-8±3^{a}	1±4^{a}	-2±1^{a}	-4±5^{a}
		%	(-13.5)	(0.0)	(-13.8)	(1.4)	(-2.4)	(-5.1)
	Men	mm	-20±5^{a*}	2±5^{b}	4±3^{b}	-15±6^{a}	0±3^{a}	-7±5^{a}
		%	(-25.6)	(2.8)	(7.0)	(-18.1)	(0.0)	(-8.6)
With 0.25% addition of MSG	Women	mm	-23±6^{a*}	17±3^{c**}	1±3^{b}	2±5^{a}	2±3^{a}	-2±4^{a}
		%	(-30.3)	(29.3)	(1.8)	(2.7)	(2.6)	(-2.8)
	Men	mm	-24±7^{a*}	5±4^{b}	4±3^{b}	-14±4^{a*}	-2±3^{b}	-4±3^{b}
		%	(-36.9)	(8.6)	(7.6)	(-16.7)	(-2.6)	(-5.3)
With 0.025% addition of IMP	Women	mm	-30±6^{a**}	2±4^{b}	-8±5^{b}	-6±3^{a}	-2±3^{a}	-8±3^{a}
		%	(-42.9)	(2.7)	(-12.7)	(-9.0)	(-2.4)	(-9.6)
	Men	mm	-20±5^{a*}	4±5^{b}	2±5^{b}	-6±5^{a}	-5±4^{a}	-2±4^{a}
		%	(-36.4)	(6.0)	(3.0)	(-7.5)	(-6.3)	-2.6)
With 0.025% addition of IMP+GMP	Women	mm	-18±7^{a*}	7±5^{b}	-6±6^{ab}	-3±2^{a}	-1±2^{a}	-4±3^{a}
		%	(-24.0)	(10.9)	(-10.5)	(-3.6)	(-1.2)	(-4.8)
	Men	mm	-16±5^{a*}	7±3^{c}	-1±3^{b}	-9±7^{a}	-5±4^{a}	-7±6^{a}
		%	(-22.2)	(10.3)	(-1.5)	(-10.8)	(-6.3)	(-9.0)

a change in pleasantness score (mm) = (evaluation 2 minutes after ingestion of test meal – initial rating); brackets provide percentage changes in pleasantness scores for test products as compared to the initial rating

† – in particular sessions the rating was made for pasta with Bolognese sauce without or with the addition of a flavour enhancer in respect of a product consumed until sated; the other test products did not contain any flavour enhancers

Significance of changes in pleasantness scores: * – $p<0.01$; ** – $p<0.001$

Mean values in the same rows, separately for both age groups, denoted with different letters are statistically different at a significance level of $p<0.05$

TABLE 5. Intake, energy value and changes in pleasantness scores of pasta with Bolognese sauce without and with the addition of flavour enhancers 2 minutes after consumption (mean±SEM).

Pasta with Bolognese sauce	Sex	Intake (g)			Energy value (kcal)			Changes in pleasantness scores (mm)*		
		Young subjects	Elderly subjects	Significance of age differences	Young subjects	Elderly subjects	Significance of age differences	Young subjects	Elderly subjects	Significance of age differences
Without the addition of flavour enahncer	Women	369±25	314±25	n.s.	341±23	291±23	n.s.	-10±6	1±4	n.s.
	Men	678±58	408±36	p<0.001	627±53	377±33	p<0.001	-20±5	-15±6	n.s.
	Significance of sex differences	p<0.001	p<0.05	-	p<0.001	p<0.05	-	n.s.	p<0.05	-
With 0.25% addition of MSG	Women	415±43	318±22	p<0.05	384±40	295±20	p<0.05	-23±6	2±5	p<0.01
	Men	693±64	427±31	p<0.001	641±60	395±29	p<0.001	-24±7	-14±4	n.s.
	Significance of sex differences	p<0.01	p<0.01	-	p<0.01	p<0.01	-	n.s.	p<0.05	-
With 0.025% addition of IMP	Women	427±27	323±24	p<0.05	395±25	298±22	p<0.05	-30±6	-6±3	p<0.01
	Men	711±71	457±38	p<0.01	657±65	423±35	p<0.01	-20±5	-6±5	n.s.
	Significance of sex differences	p<0.001	p<0.01	-	p<0.001	p<0.01	-	n.s.	n.s.	-
With 0.025% addition of IMP+GMP	Women	469±48	305±23	p<0.01	434±44	282±22	p<0.01	-18±7	-3±2	n.s.
	Men	673±64	419±40	p<0.01	623±59	387±37	p<0.01	-16±5	-9±7	n.s.
	Significance of sex differences	p<0.05	p<0.05	-	p<0.05	p<0.05	-	n.s.	n.s.	-

* a change in pleasantness scores = (evaluation 2 min after consumption – initial rating)

of age. When comparing changes in subjective sensations of young and elderly subjects after *ad libitum* consumption of the pasta, a statistically significant (p<0.01) difference was observed in the case of pleasantness ratings of pastas with the addition of MSG and those with the addition of IMP (Table 5). Sex had a significant effect on the emergence of the impact of the type of enhancer applied on the sensory--specific satiety (F=4.120, p<0.01). The results obtained in the reported paper confirm findings of other authors [Rolls & McDermott, 1991; Rolls, 1993, 1994, 1999a], that deterioration of the functioning of chemoreceptory senses observed on the elderly people may contribute to the disappearance of the phenomenon of the sensory-specific satiety and, consequently, to diminished appetite and more monotonous diet, which in turn may induce undesirable health effects. Miller *et al.* [2000] demonstrated that sex had no significant effect on the development of SSS, which has also been shown in the reported study.

Figure 1 presents the dynamics of changes in pleasantness ratings of pasta with Bolognese sauce consumed *at libitum*. The greatest drop in pleasantness scores of pasta was observed 2 min after meal termination. Also Hetherington *et al.* [1989] as well as Rolls & Rolls [1997] demonstrated that SSS occurs with the highest intensity 2 min after meal consumption, when the effect of factors linked with digestion and absorption of meal is negligible. The following regularity was observed in this case: the greater the drop in pleasantness scores after pasta consumption, the faster their increase. However, even 90 min after the consumption of pasta with sauce until sated (irrespective of its version), its perceptible pleasantness did not reach the initial score. When changes in pleasantness ratings 2 min after consumption were expressed in per cents in respect of the initial rating, the greatest change in pleasantness after the consumption of pasta with the addition of sodium inosinate was observed in women (by 42.9% and 9.0% in young and elderly women, respectively). In the case of young men, the greatest relative change was reported for the rating of pasta with sauce with the addition of MSG (by 36.9%), whereas in the elderly men – for pasta without the addition of flavour enhancers (by 18.1%). The lowest decrease in pleasantness of pasta with sauce was observed in young subjects consuming until sated pasta with the addition of only salt.

As it results from Table 5, women consumed significantly less pasta with sauce, as compared to men, irrespective of the flavour enhancer applied. Likewise, while eating until sated the elderly subjects consumed lesser amounts of the test meal than the young subjects did. Since all versions of pasta were isocaloric, differences in energy intake were analogous to food intake.

The statistical analysis did not demonstrate any significant correlation between energy value of meal consumed by young subjects and a change in perceptibility level of the pleasantness of pasta with Bolognese sauce, which indicates that the satiety evoked is sensory-specific in character [Bell *et al.*, 2003; Porrini *et al.*, 1995], and that the observed change in pleasantness does not depend on the load of calories ingested. Also a dependency between a change in perceptibility level of the pleasantness of pasta with sauce and the declared satisfaction of hunger appeared statistically insignificant in the young subjects, which is another proof for the induction of sensory-specific satiety in those subjects. In contrast, in the group of elderly subjects a significant correlation was found between a change in the level of hunger perception and a change in the level of pleasantness perceptibility. It might indicate that the satiety evoked in the elderly subjects is not linked with sensory weariness but is the effect of stomach filling. On the other hand, however, the statistical analysis did not demonstrate any significant correlation between energy value (amount) of the pasta consumed and changes in the perception level of pleasantness and hunger. This can

be explained by the fact that in the case of elderly subjects most often declared reason for the termination of consumption was "I fell full up", whereas in the case of young subjects – "the food began to taste less pleasantly", which according to Hetherington [1996] is a confirmation of the development of the sensory-specific satiety.

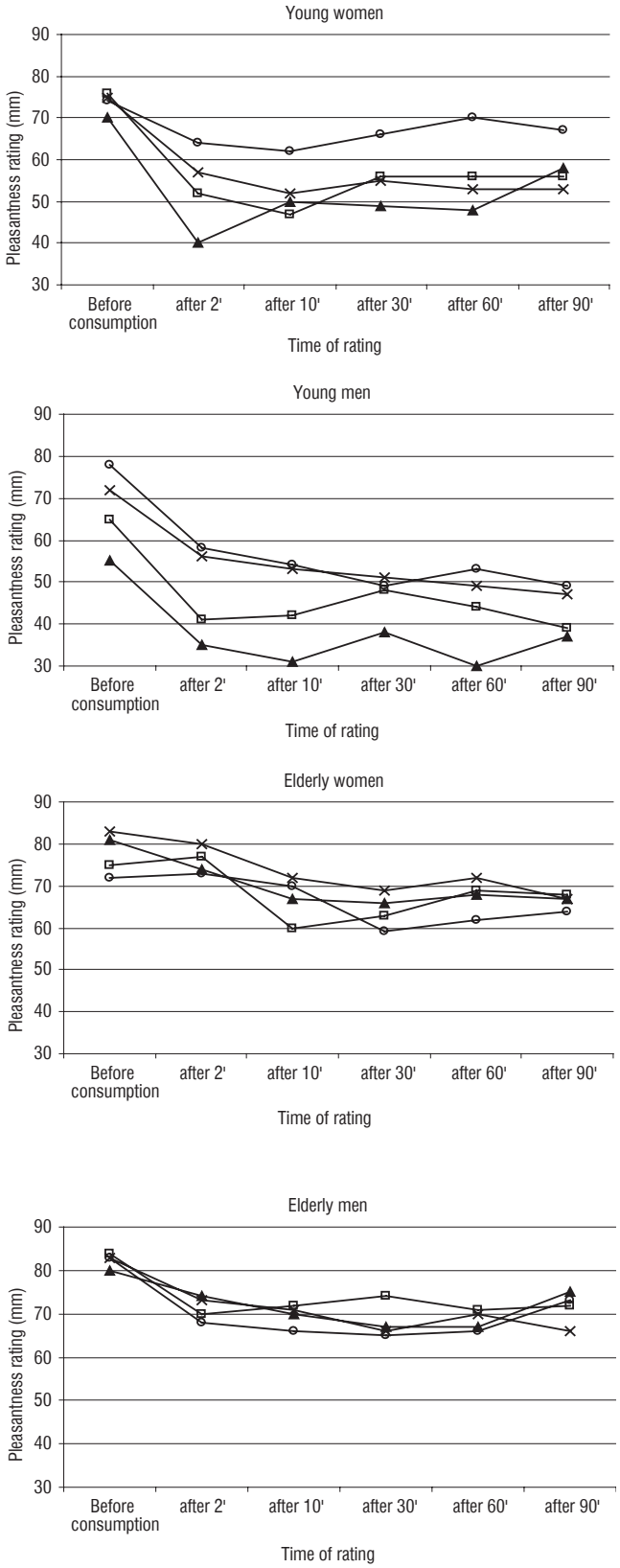

FIGURE 1. Dynamics of changes in pleasantness ratings of pasta with Bolognese sauce (-o- – without the addition of flavour enhancer, -□- – with 0.25% addition of MSG, -▲- – with 0.025% addition of IMP, -×- – with 0.025% addition of IMP+GMP) after its *ad libitum* consumption

CONCLUSIONS

1. Age had a significant effect on the development of sensory-specific satiety. The SSS occurred in the younger subjects consuming pasta with Bolognese sauce until sated and was manifested by a significant decline in its pleasantness. In subjects over 60 years of age, that phenomenon did not occur at all or occurred to a limited extent and with clearly lower intensity.

2. The addition of flavour enhancers to pasta with Bolognese sauce intensified the occurrence of the sensory-specific satiety, yet that effect depended on sex of the examined and was distinctly higher in women than in the men.

3. The perceptible decline of pleasantness after the consumption of pasta with Bolognese sauce was selective in character and occurred with the highest intensity 2 min after its *ad libitum* consumption. The stronger was the decrease, the faster the tendency of returning to initially perceived pleasantness of the produced occurred, however 90 min after consumption the perceived pleasantness of pasta with Bolognese sauce did not reach the initial level.

4. In the elderly subjects, the feeling of satiety appeared at a relatively lower intake of pasta with Bolognese sauce, as compared to the younger subjects, yet the addition of flavour enhancers had no significant effect on the energy value of the meal consumed in both age groups.

5. Post-consumption changes in pleasantness ratings of pasta with sauce in both age groups were not linked with its intake, but in the elderly subjects (contrary to the younger ones) correlated with the level of perception of hunger (satiety).

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WPŁYW INTENSYFIKATORÓW SMAKU NA WYSTĘPOWANIE ZJAWISKA SYTOŚCI SENSORYCZNIE SPECYFICZNEJ U LUDZI W ZALEŻNOŚCI OD ICH PŁCI I WIEKU

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Celem pracy była ocena wpływu intensyfikatorów smaku na występowanie zjawiska sytości sensorycznie specyficznej (SSS) u ludzi młodych i starszych obojga płci. Badania realizowano z udziałem 60 osób (30 osób młodych i 30 osób starszych, po 15 kobiet i mężczyzn w każdej grupie), które określały smakowitość produktów instant o odmiennych właściwościach sensorycznych (makaron z sosem bolońskim, kisiel cytrynowy, kaszka owocowa) przed i po spożyciu do syta makaronu z sosem bolońskim bez i z dodatkiem intensyfikatorów smaku (monoglutaminian sodu, inozynian sodu oraz mieszanina inozynianu i guanylanu sodu). Wykazano znamienny ($p<0,001$) wpływ wieku na rozwój SSS, przy czym wytworzenie tego zjawiska stwierdzono jedynie w przypadku osób młodych. Dodatek intensyfikatorów smaku do makaronu z sosem bolońskim nasilał występowanie sytości sensorycznie specyficznej, przy czym efekt ten był zależny od płci badanych osób i wyraźnie większy u kobiet niż u mężczyzn. Wykazano ponadto, że u osób starszych odczucie sytości występowało przy relatywnie mniejszym spożyciu makaronu z sosem bolońskim aniżeli u osób młodych, a dodatek intensyfikatorów smaku w obu grupach wiekowych nie miał istotnego wpływu na ilość energii pobranej z posiłkiem.