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SHORT COMMUNICATION

Are the Tastes of Polycose and Monosodium Glutamate Unique?

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Abstract

To study whether Polycose and monosodium L-glutamate (L-MSG) have unique tastes differing from the traditional four basic tastes, chemosensory profiles were established for Polycose, L-MSG and a group of related compounds (sucrose, maltose, monosodium D-glutamate (D-MSG), sodium chloride, calcium chloride). Flavors were assessed using whole-mouth tests in human subjects with nose open or clamped to reduce olfactory input. Polycose (a mixture of glucose-based oligosaccharides) had a flavor consisting of an olfactory component and a maltose-like taste. L-MSG and D-MSG profiles differed from each other, and from NaCl and $CaCl_2$. L-MSG had a lower threshold and a higher frequency of 'other' tastes than the D form. The data do not support a 'polysaccharide' taste, but suggest a chiral receptor site for 'umami' taste. **Chem. Senses 21: 341–347, 1996.**

Introduction

The theory that taste sensation is composed of four elementary taste qualities: sweet, salty, sour and bitter (Bartoshuk, 1978) is challenged by evidence for unique, non-traditional taste qualities (Hettinger *et al.*, 1990; Yamaguchi, 1991). Tastes unique to polysaccharides (Sclafani, 1987) and glutamate salts (Kawamura and Kare, 1987) have been suggested. Polycose, a mixture of glucose-containing oligosaccharides, is thought to elicit 'polysaccharide' taste (Feigin *et al.*, 1987), a taste distinct from the sweet taste. Monosodium L-glutamate (L-MSG) has long been thought to epitomize 'umami' taste, a taste that is not sweet, salty, sour or bitter (Schiffman and Gill, 1987). The existence of specific receptor systems for Polycose and L-glutamate has to be considered in molecular models of taste reception if these proposals prove true.

Polycose contains glucose oligosaccharides of 3–10 glucose units linked by α(1→4) glycosidic bonds. The average molecular weight is about 1000. Based on behavioral data, it is suggested (Nissenbaum and Sclafani, 1987) that rodents may have a distinct taste recognition system for Polycose ('polysaccharide taste'). However, rodent neural and behavioral taste responses to Polycose have properties resembling responses to salts and sugars (Giza *et al.*, 1991; Nakamura and Norgren, 1993; Formaker *et al.*, 1994; Sako *et al.*, 1994). These findings raise doubts about the uniqueness of Polycose taste, since it may have

features in common with salts and sucrose. To humans, Polycose has a taste that is somewhat sweet, but less pleasant than sugars (Feigin *et al.*, 1987). We compared chemosensory profiles of Polycose, sucrose and maltose with the nose open and closed to determine if olfaction contributes to Polycose 'taste', as it does to the tastes of other compounds with 'non-traditional taste' qualities (Hettinger *et al.*, 1990).

In the extensive literature on MSG flavor (Kawamura and Kare, 1987) the chemical basis for 'umami' taste is not fully addressed. Even though L-glutamate and related compounds are primary stimuli, nucleotides such as guanosine 5'-monophosphate (GMP) and inosine 5'-monophosphate (IMP) are also considered to have 'umami' flavor. Based on differences in chemistry, it is suggested there are two 'umami' systems, one stimulated by glutamate and the other by monophosphate nucleotides (Boudreau, 1987). Alternately, it is possible the apparent 'umami' taste of IMP in humans is due to the enhancement of the taste of glutamate normally present in saliva (Yamaguchi, 1991). Further study is needed to delineate the structural requirements for this possibly unique taste. We compare optical isomers L-MSG and D-MSG, which we expected to have distinctly different taste profiles. The 'umami' taste would be found only in the profile for L-MSG if this taste involved a specific chiral receptor for the L form.

Our results suggest the 'unique' quality of Polycose is olfactory, and the 'unique' quality of L-MSG is gustatory and mediated by a chiral receptor in humans.

Methods, results and discussion

Polycose was obtained from Ross Laboratories (Columbus, OH) and used without further purification. L-MSG (Aldrich Chemicals Co., Milwaukee, WI) was recrystallized from 80% methanol. D-MSG was prepared from D-glutamic acid (Sigma Chemical Co., St Louis, MO) by neutralization with sodium hydroxide and crystallized twice from 80% methanol. Reagent grade sucrose (Baker, Phillipsburg, NJ), maltose (Sigma), sodium chloride (Baker) and calcium chloride (Matheson, Coleman & Bell, East Rutherford, NJ) were also used. Salts were 0.01, 0.03 and 0.10 M; sugars were 0.03, 0.10 and 0.30 M. Polycose was used at 3.2, 10 and 32% (w/v), approximating in total saccharide components the molarities used for sugars.

For each compound, 10 normal human subjects, who were chosen from among 18 volunteers (eight males and 10 females, 20–50 years old), were asked to sample ('sip and spit') in random order about 10 ml of each solution from plastic cups with nose clamped (Nose Clip, Speedo Holdings, B.V., Ontario, Canada) and to choose from a list of nine descriptors (sweet, salty, sour, bitter, soapy, sulfurous, metallic, other, none), one or two descriptors that best described the flavor (Hettinger *et al.*, 1990). The subjects were then tested with the same stimuli with the nose open. The mouth was rinsed with water between stimuli. A maximum of 15 solutions were sampled in one session, within which inter-stimulus intervals approximated 2 min. Subjects most frequently chose one descriptor for a solution, but the median total frequency for the ten subjects was 12 (range = 10–15) because two descriptors were chosen in some cases. Frequency distributions across quality descriptors were statistically analysed with Fisher exact probability tests and particular frequency pairs were analysed with binomial tests.

The method used to assess chemosensory quality differs from most other studies in three ways. First, quality profiles are established only by the frequencies that taste qualities are reported. This contrasts with the subjective estimation of intensity of multiple qualities (Smith and McBurney, 1969). The task required of the subject is simplified and no individual can dominate the results. Nevertheless, profiles of frequencies that 'sweet', 'salty', 'sour' and 'bitter' descriptors are chosen by a group of subjects are often similar to profiles of average 'sweet', 'salty' 'sour and 'bitter' intensity ratings (Sandick and Cardello, 1981).

Secondly, chemosensory qualities such as 'soapy', 'metallic', 'sulfurous' and 'other' were used in addition to 'sweet', 'salty', 'sour', 'bitter' and 'none'. This provides a greater range of possible perceived oral sensations, even though they may not all be genuine tastes. However, compared to giving subjects unlimited use of descriptors (Halpern, 1987), limiting choices greatly simplifies statistical analysis of frequency distributions (Frank *et al.*, 1995).

Finally, it is critical to control for possible contributions of smell in taste testing. The olfactory system is very sensitive and can detect trace impurities that may be present in taste stimuli. Even a solution that appears to be odorless when sniffed may, when tasted, release odorants into the confined, warm environment of the nasopharynx and into the olfactory cleft where they may be detected. It is almost impossible to make a subjective distinction between taste and smell when stimuli are sampled in usual 'whole-mouth' tests. Nose clamps eliminate retronasal olfaction by blocking tidal airflow through the nose. Although more elaborate methods have been described (Mozell *et al.*,1969; Faurion, 1993), we find that nose clamps adequately reduce olfactory

input to render 'tasteless' such highly odorous compounds as L-cysteine (Hettinger *et al.*, 1990).

Frequency distributions of quality descriptors for the saccharides tested are presented in Figure 1. Patterns of responses to sucrose (Figure 1A) did not differ across concentrations, but patterns for Polycose (Figure 1B) and maltose (Figure 1C) did ($P \leq 0.001$). Sucrose was clearly sweet at all concentrations, but subjects frequently reported that 0.03 M maltose and 3.2% Polycose had no taste. Patterns of responses to Polycose with the nose open differed from patterns with the nose closed ($P \leq 0.001$), particularly at 3.2% ($P \leq 0.001$), whereas, the nose did not affect patterns for maltose and sucrose. Polycose, at 3.2 %, was frequently found 'sweet' with the nose open, although it had no taste with the nose closed.

Collapsed across concentrations (Figure 1, totals), patterns of responses to sucrose, Polycose and maltose all differed ($P \leq 0.001$) with the nose open. Besides the sweet quality, a prominent 'other' quality was detected for Polycose with the nose open that did not appear with the nose clamped ($P = 0.01$), whereas maltose was described as salty, sour, bitter or had no taste. With the nose closed (Figure 1, totals), patterns for Polycose and maltose differed from sucrose ($P \leq 0.001$), but not from each other. The difference reflects more frequent reports of 'no taste' for maltose ($P < 0.002$) or Polycose ($P < 0.001$) than sucrose with the nose clamped.

Frequency distributions of quality descriptors for the salts are presented in Figures 2 and 3. Patterns of response for sodium chloride (Figure 2A), calcium chloride (Figure 2B) and monosodium D-glutamate (Figure 3A) differed across concentration ($P \leq 0.002$); patterns for monosodium L-glutamate did not (Figure 3B). The nose clamp did not significantly affect the overall patterns for any of these salts. However, the descriptor 'sulfurous', which implicates olfactory input (Hettinger *et al.*, 1990), was used more frequently to describe L-MSG than D-MSG ($P = 0.02$) and there was a tendency for subjects to use this descriptor more frequently with the nose open than closed ($P = 0.09$). In the past, contaminants were shown to contribute to the 'meaty' flavor of L-MSG (Sjöström, 1972), but we used highly purified material. At 0.03 M, the predominant taste attributed to NaCl was salty, but $CaCl_2$ was bitter. At 0.10 M, NaCl remained salty, but $CaCl_2$ was bitter and salty. Based on effects of adaptation to NaCl on intensity estimates for a variety of salts (Smith and McBurney, 1969; Smith and van der Klaauw, 1993), saltiness is thought to be coded by a 'single mechanism' in humans. Our data suggest that $CaCl_2$ stimulates this mechanism at 0.10 M, but not at lower concentrations.

Patterns for the taste qualities attributed to the isomeric forms of monosodium glutamate (Figure 3) suggest that L-MSG has a lower taste threshold than D-MSG. L-MSG was detected by most subjects even at 0.01 M. Over all concentrations, the number of 'no taste' responses was significantly greater for D-MSG than L-MSG ($P < 0.001$). This result is consistent with earlier reports that the D form

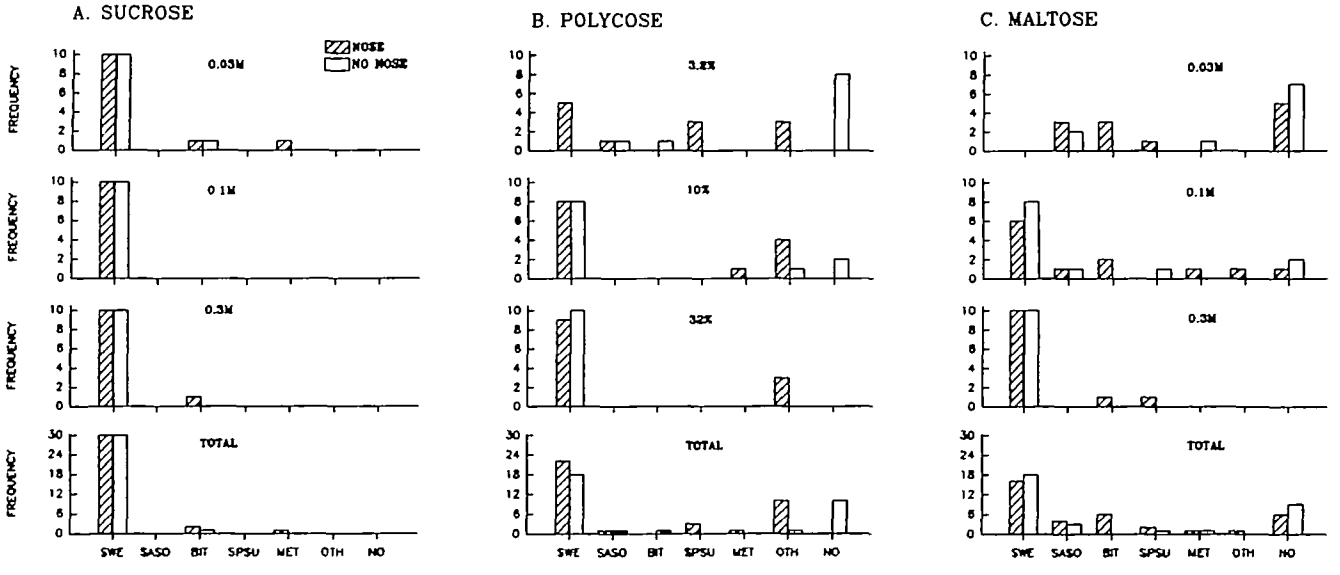

Figure 1 Distribution of quality descriptors for 10 normal subjects in whole-mouth tests of three concentrations of sucrose **(A)**, Polycose **(B)** and maltose **(C)** obtained with the nose open (NOSE) or closed (NO NOSE). SWE = sweet, SASO = salty or sour, BIT = bitter, SPSU = soapy or sulfurous, MET = metallic, OTH = other and NO = no taste. The results collapsed across concentration are presented in the TOTAL distribution.

is a weaker stimulus than the L form (Yamaguchi, 1991). Also consistent with this difference between the isomers of MSG is our finding that the pattern for L-MSG does not significantly change with concentration. The subjects chose a variety of descriptors for the taste quality of L-MSG at all three concentrations.

In Figure 2 and 3 (totals), data for the salts have been collapsed across concentrations. Patterns for the three sodium salts, combined for nose-open and nose-closed conditions, differ from each other ($P \leq 0.001$). This difference is partly based on the frequencies that subjects detected no taste for the three salts. However, patterns for the three sodium salts also differ ($P \leq 0.02$) at 'equally salient' concentrations (i.e. 30 mM NaCl, 100 mM D-MSG and 10 mM L-MSG), for which one subject detected no taste. NaCl is primarily salty, but also bitter. D-MSG is salty and soapy-metallic. L-

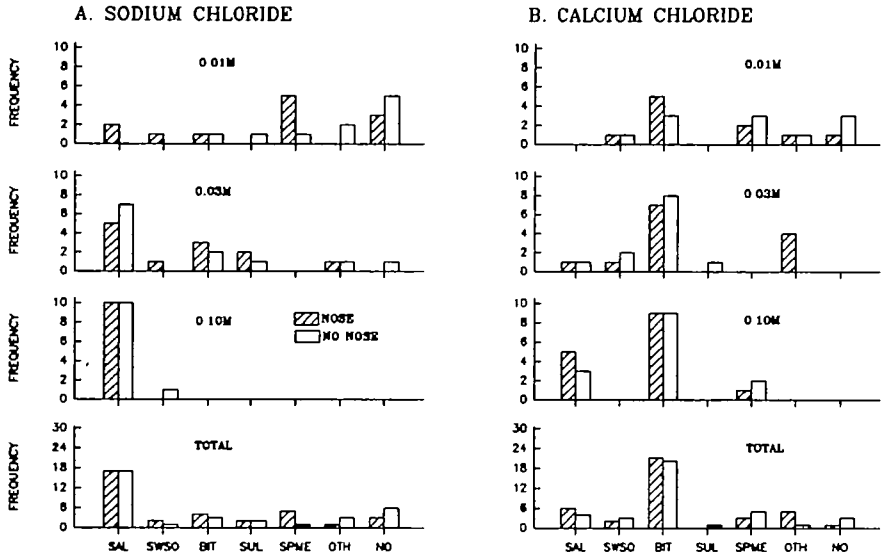

Figure 2 Distribution of quality descriptors for 10 normal subjects in whole-mouth tests of three concentrations of **(A)** sodium chloride and **(B)** calcium chloride with the nose open (NOSE) and closed (NO NOSE) SAL = salty, SWSO = sweet or sour, BIT = bitter, SUL = sulfurous, SPME = soapy or metallic, OTH = other and NO = no taste The results collapsed across concentration are presented in the TOTAL distribution.

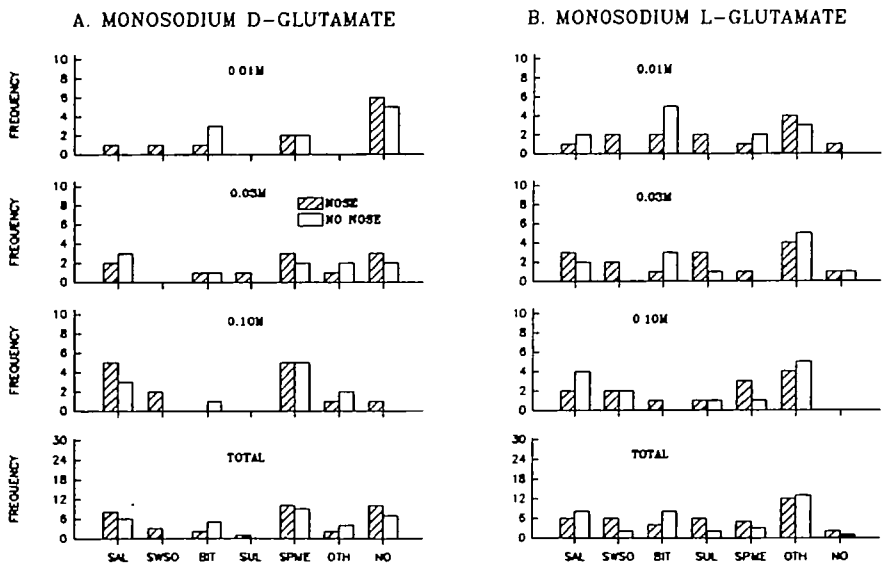

Figure 3 Distribution of quality descriptors for 10 normal subjects in whole-mouth tests of three concentrations of monosodium **(A)** D-glutamate and **(B)** monosodium L-glutamate with the nose open (NOSE) and closed (NO NOSE). SAL = salty, SWSO = sweet or sour, BIT = bitter, SUL = sulfurous, SPME = soapy or metallic, OTH = other and NO = no taste. The results collapsed across concentration are presented in the TOTAL distribution.

MSG is bitter, but also has a prominent 'other' taste quality. This 'other' quality may correspond to 'umami'. Although monosodium L-glutamate is thought to have a unique taste called 'umami', D-MSG is reported to have no 'umami' taste (Yamaguchi, 1991). In our study, D-MSG was frequently described as salty, bitter, soapy and metallic; but 'other' was used much less frequently than for L-MSG ($P < 0.001$). 'Salty' was used equally for the two isomers, which share the sodium cation. Subjects tended to use 'sweet', 'sour' and 'bitter' more frequently for the L than the D form ($P = 0.05$).

The current study with human subjects indicates that Polycose has an 'other' quality that can be eliminated by nose clamps, but L-MSG does not. It is interesting that an olfactory quality detected in Polycose at low concentration was described as 'sweet', implying an association between presumed olfactory contaminants and sugar taste. Dry Polycose has a slight vanilla-like ('sweet'?) odor that may be characteristic of sugar breakdown products and may provide a natural cue for the presence of sugars. When effects of olfaction are eliminated, Polycose and maltose at equimolar concentrations have similar quality profiles. Thus, for human taste, it appears that Polycose is no more unique than maltose. Results of the one previous study on Polycose in humans, which compared intensity ratings for concentration series of sucrose, maltose and Polycose (Feigin *et al.*, 1987), are in general agreement with the current study. Maltose was rated sweeter than Polycose at concentrations higher than 0.1 M, although the overall flavor ratings for the two stimuli were about equal. The non-sweet flavor of Polycose suggested by this result may coincide with the olfactory component discovered in the present study.

When we compared quality profiles of L-MSG to those of D-MSG, NaCl and $CaCl_2$, no olfactory component was observed for the overall patterns for any of the salts. However, there was a hint of olfactory impact in the subjects' use of the descriptor 'sulfurous' for MSG. 'Sulfurous', 'soapy' and 'metallic' are used to describe olfactory perceptions that can be blocked by nose clamps (Hettinger *et al.*, 1990). However, these terms were used to describe L and D forms, suggesting olfaction may not be relevant for 'umami'. L-MSG had a complex taste to our subjects that was partly described by the traditional qualities 'salty', 'sweet', 'sour' and 'bitter'. This result is consistent with the previous studies demonstrating use of multiple traditional quality descriptors for L-MSG (Halpern, 1987). However, in contrast to the other salts, including D-MSG, L-MSG had an undefined 'other' quality. 'Other' was used equally with the nose clamped and nose open for MSG, suggesting it was an 'other' taste. The more frequent use of non-traditional than traditional descriptors for L-MSG parallels the observation that >50% of the intensity of L-MSG is 'left over' after rating intensities of the traditional qualities (Schiffman and Gill, 1987), a finding that is controversial (Dehan *et al.*, 1994). When given freedom to choose any word to describe the taste of L-MSG, subjects use the names of foods and 'soapy' as frequently as any of the four traditional taste qualities (Halpern, 1987).

The fact that L-MSG and D-MSG have significantly different quality profiles, especially in the 'other' category, indicates that there may be a unique receptor for L-glutamate. Such a receptor would necessarily be chiral, or selective for one optical isomer, in this case preferring the L form over the D form. Chirality in taste is well known, particularly for the sweet or bitter tastes of amino acids (Shallenberger, 1992). As in the case of studies of L-glutamate as a neurotransmitter, L-glutamate taste receptors could be probed with analogs. It is possible a glutamate taste receptor is similar to known neural glutamate receptors, just as taste receptors for sodium salts are thought to be equivalent to epithelial sodium channels. DL-homocysteic acid, a glutamate analog, has an 'umami' taste (Faurion, 1991). This is significant, as it suggests common features with brain glutamate receptors. Furthermore, it appears to eliminate the possibility that contaminants or metabolic products are responsible for 'umami' flavor. It is possible that 'umami' substances L-glutamate or GMP directly activate glutamatergic synaptic receptors or second messenger systems rather than specific taste receptors on apical membranes of taste-bud cells.

Neurophysiological and behavioral data on Polycose and MSG from rodents and primates bear on the results of our study. The special properties of Polycose were first discovered in rats (Sclafani, 1987). Ionic contaminants in this material are detected in neural recordings from hamsters (Formaker *et al.*, 1994) and rats (Giza *et al.*, 1991) when the tongue is water-adapted, but not in recordings from saliva-adapted alert rats (Nakamura and Norgren, 1993) or alert cynomolgus monkeys (Plata-Salamán *et al.*, 1993). Consistent with the neurophysiological results in alert animals, an aversion to Polycose does not generalize to ionic taste stimuli in hamsters (Formaker *et al.*, 1994). In the current study, Polycose did not elicit ionic taste qualities of salty, sour or bitter in humans. To make a firm conclusion about the nature of Polycose taste it is essential to work with material of the highest possible purity. Since Polycose

contains an olfactory component, as well as salts and oligosaccharides of varying chain length, behavioral, neurophysiological and psychophysical studies may be measuring the effects of different components.

In contrast to Polycose, the special taste properties of MSG were first described for humans (Ikeda, 1909). Neurophysiological studies of non-human mammalian species do not typically report strong and specific responses to L-MSG and other 'umami' substances (Boudreau, 1987). Ten mM L-MSG stimulates sugar-sensitive *chorda tympani* neurons of chimpanzees (Hellekant and Ninomiya, 1991) and 100 mM L-MSG activates sugar-sensitive and NaCl-sensitive brainstem neurons in rats (Nishijo *et al.*, 1991), a species in which a learned aversion to L-MSG generalizes to NaCl and sucrose (Yamamoto *et al.*, 1991). Our data provide little support for a sweet taste of L-MSG in humans, nor do neurophysiological data from forebrain neurons of cynomolgus monkeys (Baylis and Rolls, 1991; Smith-Swintosky *et al.*, 1991). Mice can discriminate behavioraly between L-MSG and NaCl or L-MSG and sucrose (Ninomiya and Funakoshi, 1989a); but this discrimination is likely mediated by the glossopharyngeal nerve rather than the chorda tympani nerve (Ninomiya and Funakoshi, 1989b). Differences between taste-bud fields and differences among species may be keys to the study of the taste of L-MSG in non-humans (Boudreau, 1987).

Conclusions

Response frequencies are useful for establishing chemosensory quality profiles. The use of nose clamps is a simple and effective means for determining the role of olfaction in chemosensory tests. Without olfactory input, the taste of oligosaccharide components of Polycose in humans is sweet and similar to that of maltose. MSG has multiple taste qualities, including a unique 'other' taste that appears to be based on a chiral receptor system for L-glutamate.

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