R78-52

EFFECTS OF FLOW RATE ON TASTE INTENSITY RATINGS

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Abstract. The effects of stimulus flow rate on perceived taste intensity were studied in man using five concentrations of each of four stimulus compounds (sodium chloride, hydrochloric acid, quinine hydrochloride, and sucrose) and six different flow rates from 1.2 to 12.0 cc/sec. All stimuli were presented through a tongue chamber. Perceived taste intensity increased monotonically with flow rate for every stimulus condition tested. Psychophysical functions calculated across flow rates (rather than across physical concentrations) support the view that flow rates mimic physical concentration.

1. Introduction

Rate of stimulus presentation has rarely been studied in human or animal taste research. Cohen, Hagiwara and Zotterman (1955) observed that the response of single fibers of the cat's chorda tympani was linearly related to the flow rate of water. Switsky (1963) demonstrated a marked reduction of response of summated rat chorda tympani activity when a stimulus solution was flowed at less than 0.21 cc/sec over the anterior surface of the tongue.

In research on humans, Feallock (1965) measured the perceived taste intensity of quinine hydrochloride solutions (QHCl) presented to small areas of the dorsal tongue surface at various concentrations and at various rates of stimulus presentation. He found that for 0.02 mM and 0.06 mM QHCl, perceived intensity increased with flow rates from 1.7 cc/sec to 4.4 cc/sec and then decreased at 14.6 cc/sec. At a very low QHCl concentration (0.002 mM), he observed a decline in perceived intensity over the same range of flow rates. More recently Meiselman, Base and Nykvist (1972a) examined the effect of flow rate on magnitude estimation of taste intensity for 1.0 *M* solutions of sodium chloride (NaCl) and sucrose presented in a tongue chamber. They reported a significant increase in perceived intensity when the rate of a stimulus presentation was increased from 2.0 to 5.0 cc/sec and again when it was increased to 8.0 cc/sec. This is consistent with Feallock's work with QHCl and supports the hypothesis that perceived taste intensity varies with the rate of stimulus presentation.

Although the effects of flow rate have not been examined parametrically in the past, several researchers have controlled and reported flow rate. Flow rate is usually specified at a value between 2.5 and 5.0 cc/sec. Some investigators have reported the total volume of stimulus solution flowed over the tongue, others have specified only the total time of stimulus presentation, while others have specified both volume and duration but have not indicated whether flow rate was constant (see Meiselman *et al.*, 1972a).

The present experiment examined the relationship between flow rate and perceived

Chemical Senses and Flavor **2** (1977) 515–522.

taste intensity over an extended range of flow rates for five concentrations of four solutions representing the four traditional taste quality categories.

2. Method

In order to maintain constant flow rate of test solutions, a tongue chamber was constructed from clear Plexiglas, stainless steel pins, plastic tubing and connectors. The tongue chamber construction and its characteristics in terms of the stimulus presentation are described in detail by Meiselman *et al.* (1972). The significant advantage of using this tongue chamber delivery system relates to its ability to produce a uniform flow and dispersion of test solutions over approximately ninety percent of the lateral surface of the anterior division of the tongue. Meiselman *et al.* (1972a) determined that the maintenance of stimulus strength, the production of concomitant changes in pressure, and the turbulence of the stimulus within the tongue chamber did not significantly contribute to any perceived changes in the intensity of a solution resulting from a change in flow rate through the tongue chamber. Either distilled water or a test solution could be directed into the tongue chamber at any desired flow rate ranging from 0–12.0 cc/sec. The modification of apparatus described by Meiselman *et al.* (1972a) ensured that the tongue chamber remained filled with the stimulus compound and that the desired flow rate was obtained when a flow rate as low as 1.0 cc/sec was used.

Three valves controlling the flow of the solution were affixed to the apparatus behind a wooden screen, outside of the subject's field of vision. The valve controlling the flow of distilled water which preceded each test solution was calibrated to deliver a constant flow of 5 cc/sec. The flow rate of the taste solutions was controlled by adjusting one of two specially constructed flow meter regulators (Fischer and Porter model 53RT2110, Series A2). By adjusting these flow rate regulators any flow rate ranging from 0–15 cc/sec with liquids of specific gravity 1.0 and viscosity 1.0 c.p.s. could be attained. The flow rate regulators could be connected by plastic tubing to any one of 5 one-gallon polyethylene bottles holding one concentration of a taste solution. A sixth polyethylene bottle containing distilled water was connected in a like manner to the valve calibrated for the 5.0 cc/sec delivery. All bottles sat in a water bath maintained at 34 ± 1°C and were pressurized with nitrogen gas to 2 p.s.i. Since it was not feasible to increase the nitrogen pressure above 2 p.s.i. the maximum flow rate with this system was 12.5 cc/sec; further increases in nitrogen pressure resulted in fluid leaks at tubing junctures.

Subjects were 40 male volunteers, ranging in age from 22–27 years, chosen from laboratory personnel at the U.S. Army Natick R & D Command. Four groups of ten subjects each were used to determine the effects of six flow rates on the perceived intensity of five concentrations of Sucrose, NaCl, QHCl, or HCl. An experimental session involved only one of the four types of stimulus compounds and each subject served in only one session. The concentrations of the Sucrose and NaCl test solutions were 0.1, 0.18, 0.34, 0.58, and 1.00 *M*. The HCl test solutions were 0.0004, 0.0020, 0.0066, 0.0073, 0.0145 *M* and the QHCl test solutions were 0.0001, 0.00016, 0.00025, 0.00039,

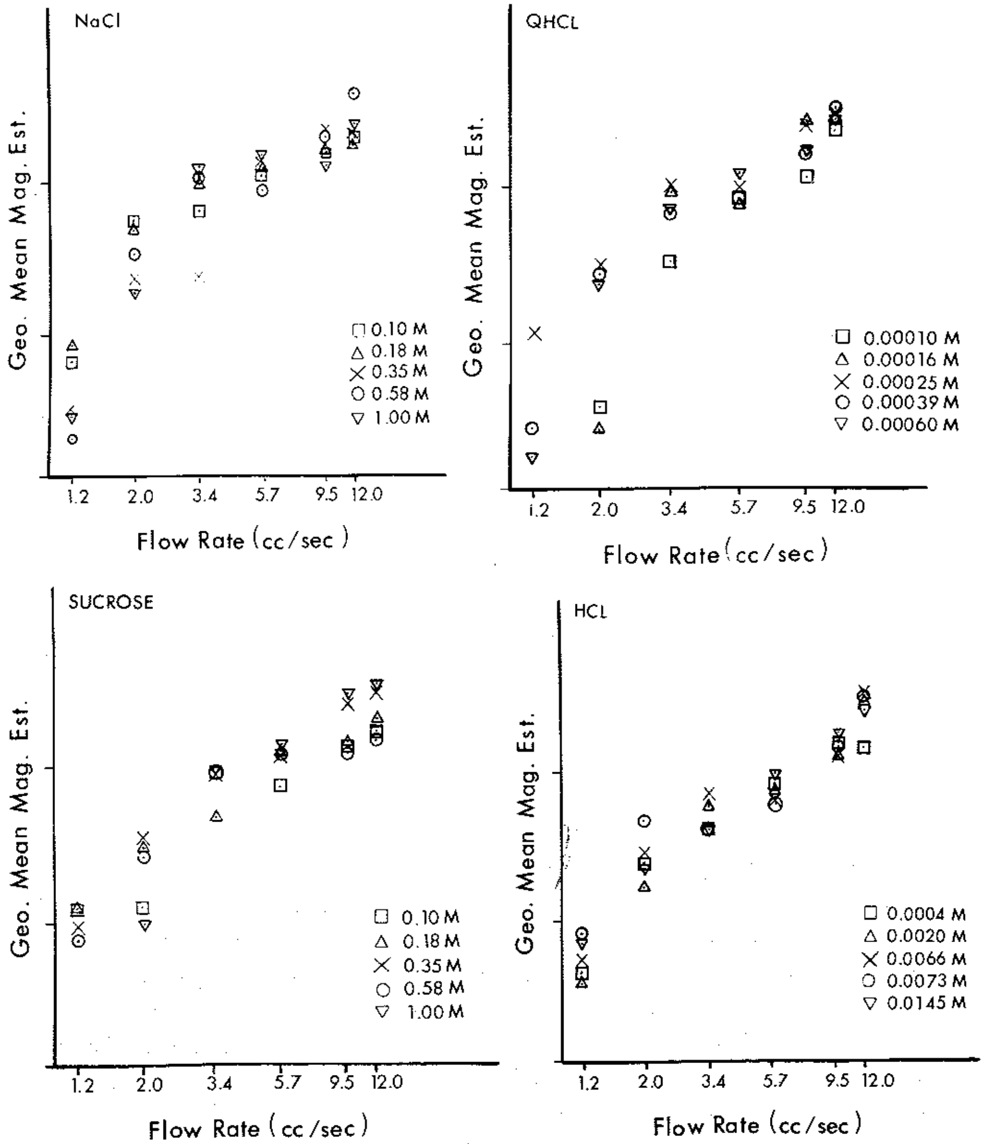

Fig. 1. Geometric mean magnitude estimates as a function of flow rate. The key indicates the data points for each stimulus concentration. The ordinate is marked at geometric mean estimates of 1, 3, 10 units. Connecting line segments are omitted for ease of viewing. Exponents of the best fitting straight lines and Pearson–Product Moment Correlations are shown in Table I.

0.00060*M*. All solutions were prepared from reagent grade materials and distilled water (refractive index = 1.3330), and placed in the one-gallon polyethylene bottles. They were presented at flow rates of 1.2, 2.0, 3.4, 5.7, 9.5, and 12.0 cc/sec in the tongue chamber.

Before each testing session subjects were seated before the apparatus and instructed

TABLE I

Data from lines fit for each concentration across flow rates. The exponent was calculated from regression analysis and the fit from the Pearson Product–Moment Correlation. A different line was fit for each concentration across all flow rates.

Stimulus	Conc. (*M*)	Exponent	Correlation
NaCl	0.10	0.65	0.92*
	0.18	0.59	0.91*
	0.35	0.92	0.94**
	0.58	0.91	0.91*
	1.00	0.87	0.90*
HCl	0.0004	0.74	0.96**
	0.0020	0.86	0.97**
	0.0066	0.79	0.95**
	0.0073	0.68	0.94**
	0.0145	0.78	0.99**
QHCl	0.00010	1.85	0.90
	0.00016	1.96	0.90
	0.00025	0.71	0.97***
	0.00039	0.91	0.95**
	0.00060	0.99	0.93**
Sucrose	0.10	0.63	0.92**
	0.18	0.62	0.98***
	0.35	0.76	0.98***
	0.58	0.64	0.93**
	1.00	1.30	0.93**

to rinse their mouth with distilled water which was presented to them in a 250 ml beaker. The subject was then presented once with the standard, which consisted of a 5.7 cc/sec presentation for 5 sec of a taste solution. The standard was assigned a value of ten. Subjects were asked to estimate the magnitude of all later solutions using numbers in proportion to the strength of the standard according to the procedure of magnitude estimation. One 5 sec presentation of each of the six flow rates followed the standard. The standard and each test solution were preceded by at least a 15 sec intertrial interval. During this interval subjects reported magnitude estimation of total perceived taste intensity, rinsed their mouth with distilled water, and the tongue chamber was flushed with distilled water. The presentation of all stimuli was preceded by a 5 sec flow of distilled water at 5.0 cc/sec. During an experimental session the five concentrations of one stimulus compound were presented to each subject at the six flow rates for each of the concentrations; each stimulus combination (concentration and flow rate) was presented once. Order of conditions was random.

TABLE II

Least significant difference tests on arithmetic mean magnitude estimates. Means which are *not* significantly different are underlined; means which are significantly different are not underlined.

NaCl Conc. (M)	Flow rate (cc/sec) 1.2	2.0	3.4	5.7	9.5	12.0
0.1000	3.5	12.2	10.6	13.5	17.7	21.1
0.1800	6.3	10.4	11.5	13.0	15.3	14.9
0.3500	3.0	6.9	10.9	14.4	16.7	16.0
0.5800	1.4	8.6	11.5	11.6	16.8	21.5
1.0000	1.9	6.7	12.2	14.0	13.5	17.8

QHCl Conc. (M)	Flow rate (cc/sec) 1.2	2.0	3.4	5.7	9.5	12.0
0.00010	0.7	4.0	7.8	12.0	12.0	17.5
0.00016	0.8	5.5	10.9	10.0	19.0	21.0
0.00025	4.5	8.4	10.7	12.3	20.3	19.5
0.00039	4.1	7.7	10.1	13.2	14.0	20.0
0.00060	4.7	7.1	9.8	13.4	15.3	19.1

Sucrose Conc. (M)	Flow rate (cc/sec) 1.2	2.0	3.4	5.7	9.5	12.0
0.1000	5.4	5.1	10.8	10.7	15.0	13.8
0.1800	5.3	6.4	10.0	12.5	14.6	16.0
0.3500	3.8	5.7	11.0	13.5	19.1	19.8
0.5800	4.1	5.5	10.6	12.0	12.9	13.5
1.0000	3.4	4.3	10.4	14.3	19.7	19.6

HCl Conc. (M)	Flow rate (cc/sec) 1.2	2.0	3.4	5.7	9.5	12.0
0.0004	3.4	6.0	9.6	10.7	13.7	13.9
0.0020	4.0	7.3	8.9	12.8	16.1	21.6
0.0066	3.2	6.8	9.6	11.0	15.5	21.4
0.0073	4.2	9.2	7.7	9.2	13.6	20.8
0.0145	3.4	5.6	8.0	12.3	17.3	22.1

3. Results

Geometric means were calculated for each concentration at each flow rate and are plotted in Figure 1. It should be noted that a different function is plotted for each concentration across all flow rates, rather than the more conventional plotting across concentrations. In other words, the middle value flow rate at each concentration served as the standard for judging the perceived intensity of all flow rates of that concentration. Since different standards were used with different concentrations, it is impossible to directly compare concentrations. Linear regression analyses were used to develop equations for each line, and permit calculation of the slope of the lines. A significant linear relationship was shown for each concentration of each compound by Pearson Product–Moment correlations. The slopes of the straight lines and the correlations are shown in Table I.

Analyses of variance were carried out on the raw scores for each concentration and each stimulus across the six flow rates. Each analysis of variance showed a highly significant effect of flow rate; with only one exception ($p < 0.005$) this effect was significant at the 0.001 level of significance. More specific Least Significant Difference tests (Li, 1964) were carried out to determine whether significant differences exist between flow rates for each stimulus and each concentration. The results are shown in Table II, which contains the arithmetic means of the magnitude estimates. The arithmetic mean was used to permit use of these statistics. In Table II means which are *not* significantly different are underlined, while means which are significantly different are not underlined. Overall, perceived taste intensity increased monotonically with increased flow rate. At every concentration of every stimulus there was a significant effect of flow rate within the limits of the experiment.

4. Discussion

The present study extends current knowledge about the effects of flow rate and also contributes to our understanding of how flow rate functions as a psychophysical variable. Within the conditions of the present experiment, perceived taste intensity increased monotonically with flow rate. Meiselman *et al.* (1972) had reached this conclusion for flow rates of from 2 to 8 cc/sec with two stimulus materials (NaCl and sucrose) at only one concentration (1.0 *M*). The present study extends the results to quinine and hydrochloric acid, to a wide range of concentrations for each stimulus, and to an extended range of flow rates.

Feallock (1965) had reported that perceived taste intensity increased with flow rates up to 4.4 cc/sec but decreased at 14.0 cc/sec. Since the present experiment does not contain data above 12.0 cc/sec no specific test has been done of the previous finding of a decrement with higher flow rates. However the present experiment does extend Feallock's upper limit of a positive relationship between taste intensity and flow rate to at least 12.0 cc/sec. Furthermore, the present study failed to replicate Feallock's observation of reduced taste intensity of weak quinine with higher flow rates.

TABLE III

Comparison of range of previously reported psychophysical function exponents with range in present study

	Previous range[a]	Present range
NaCl	0.59–0.92	0.41–0.91
HCl	0.70–1.48	0.68–0.86
QHCl	0.30–0.85	0.71–1.96[b]
Sucrose	0.46–0.93	0.62–1.30[c]

[a] From Meiselman *et al.* (1972).
[b] Only the two concentrations were greater than 0.99.
[c] Only the one highest concentration was greater than 0.76.

Among the mechanisms postulated by Meiselman *et al.* (1972) to account for the flow effects was that flow rate mimics physical concentration by controlling the rate at which the stimulus is made available to the receptor sites. Since that time there has been an increasing interest in the role of rate of stimulus adsorption to receptor sites (Faull and Halpern, 1972; Heck and Erickson, 1973; Smith, 1975; Smith and Bealer, 1975; Smith, Steadman and Rhodine, 1975). If flow rate mimics physical concentration then psychophysical functions of response magnitude plotted as a function of flow rate rather than as a function of solution concentration should yield results similar to the latter plotting. These functions are well fit by power functions as indicated by the significant linear relationship on the log–log plot. Furthermore, the slopes of the log–log functions, in other words the exponents, generally fall within the ranges of exponents typically determined for psychophysical functions of concentration rather than of flow rate. For example, Meiselman *et al.* (1972b) showed that published exponents for NaCl fell within the range of 0.41–0.91 for experiments done with a flowing stimulus rather than a sipped stimulus. In the present experiment the exponents for different concentrations across all flow rates (Table I) varied from 0.59–0.92, a remarkable similarity. The results for all stimuli are shown in Table III. These data indicate that, psychophysically, flow rate does mimic concentrations although the mechanism for this is not clear. In several instances the straight line functions in Figure 1 appear to not fit the lowest flow rate. Therefore exponents were calculated for all flow rate functions at each concentration leaving out the lowest flow rate. In general, the exponents were reduced but the range of exponents for each compound at various concentrations remained about the same.

The present experiment has extended the findings that perceived taste intensity increases with flow rate over a wide range of flow rates, with a wide range of concentrations, for all four traditional taste quality categories. Further the suggestion is suported that, psychophysically, flow rate functions like concentration.

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