*Attention, Perception, & Psychophysics*
*2009, 71 (5), 1167-1173*
*doi:10.3758/APP.71.5.1167*

# The effect of stimulus delivery technique on perceived intensity functions for taste stimuli: Implications for fMRI studies

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Classic psychophysical studies have provided significant information on the psychophysical functions for taste stimuli. With the advent of fMRI, studies are being conducted that provide insight into central processing of gustation in humans. However, fMRI experiments impose physical limitations on stimulus delivery. In the present study, we compared psychophysical functions relating perceived intensity to concentration, derived from previous studies that used the traditional sip-and-spit and dorsal flow delivery techniques, to psychophysical functions generated in this study using a simulated stimulus delivery technique (SSDT). The SSDT delivered minute quantities of taste stimuli to the dorsal surface of the tongue, just as in an fMRI scanner. As was hypothesized, the results indicated that slopes of intensity functions were dependent on the type of stimulus delivery technique. The SSDT resulted in slopes that were more similar to those generated by dorsal flow than by sip-and-spit stimulus delivery techniques, suggesting the importance of considering the influence of stimulus delivery on psychophysical response in designing and interpreting experiments.

Psychophysical research on taste has consistently employed two techniques for stimulus delivery: sip-and-spit and dorsal flow. The classic sip-and-spit technique involves the participant's sampling 5–20 ml of a liquid taste stimulus, swirling the solution around in the mouth, and expectorating the contents (Bartoshuk & Cleveland, 1977; Meiselman, 1968, 1971; Moskowitz, 1970; Murphy & Cain, 1980; Murphy, Cain, & Bartoshuk, 1977; Schiffman & Clark, 1980; Stevens, 1969). This technique stimulates the whole mouth, which closely represents the way humans consume food (Meiselman, 1971). Dorsal flow delivers the stimulus over the extended anterior dorsal surface of the tongue while the lips are closed to prevent stimulation of the remainder of the oral cavity (Bartoshuk, 1975; DuBose, Meiselman, Hunt, & Waterman, 1977; McBurney, Kasschau, & Bogart, 1967; Meiselman, 1971; Meiselman, Bose, & Nykvist, 1972; Meiselman & DuBose, 1976; Smith, 1971). This technique prevents whole-mouth stimulation and limits saliva from mixing with the tastant, which has been shown to affect receptor binding (Meiselman, 1971).

The slope and intercept of a psychophysical function characterize the relationship between perceived intensity of the stimulus and its concentration. The slope reflects the rate of growth in intensity as a function of concentration. Previous studies have suggested that slopes of functions relating perceived taste intensity to concentration are dependent on the technique used to deliver the stimulus and the area of tongue stimulated (Bartoshuk, 1968; Collings, 1974; Lawless, 1987; Meiselman, 1971). Specifically, psychophysical functions for intensity of taste stimuli differ between sip-and-spit and dorsal flow techniques (Meiselman, 1971).

Slopes of functions relating perceived intensity to concentration may differ as a function of concentration (Smith, 1971). Moreover, the slopes of functions relating perceived intensity to concentration may vary as a function of the type of stimulus delivery technique (Meiselman, 1971). And, finally, the relationship among concentration, perceived intensity, and stimulus delivery technique are dependent on the quality of the stimulus. Thus, differences in the psychophysical function of perceived intensity to

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concentration for taste stimuli between sip-and-spit and dorsal flow may result from the relationship among the stimulus quality, concentration, and stimulus delivery technique.

Functional magnetic resonance imaging (fMRI) holds great promise for elucidating central mechanisms of taste. In the context of fMRI experiments, the confines of being in the scanner impose a number of physical limitations that influence the stimulus delivery technique (e.g., complicating swallowing because of the supine position, limiting head movement, etc.), resulting in stimulus delivery techniques that are significantly different from those used in behavioral experiments. However, stimulus concentrations used in fMRI experiments are often based on sip-and-spit and dorsal flow techniques. Expanding the current chemosensory stimulus delivery techniques to new methodologies (e.g., taste stimulation during fMRI) is important for the advancement of taste research. This requires applying valid and reliable psychophysical techniques, such as sip-and-spit and dorsal flow, in novel ways that will help meet the demands of new methodologies in taste research. Thus, it is important to understand how the confines of fMRI affect the relationship among stimulus quality, concentration, and stimulus delivery technique within the context of fMRI.

The present experiment examined psychophysical functions using the so-called *simulated stimulus delivery technique* (SSDT), a taste stimulus delivery technique that simulates a delivery procedure that has been utilized within the confines of fMRI experiments (Haase, Cerf-Ducastel, Buracas, & Murphy, 2007; Haase, Cerf-Ducastel, & Murphy, 2009; Stice, Spoor, Bohon, & Small, 2008). During the psychophysical testing in the present experiment, the participant was in an upright position. The SSDT involved the participant's placing a plastic syringe on the anterior dorsal surface of the tongue, approximately 0.5 cm behind the tip. The stimuli (0.3 ml, in boluses of 50 $\mu$l) were allowed to flow to the lateral edges of the tongue and were swallowed. The aim was to simulate the arrival of the stimulus and the psychophysical experience. Other aspects of stimulus delivery in the scanning experiment (computer control of taste stimuli, liquid delivery inside the magnet, swallowing, head motion) were addressed elsewhere (Haase et al., 2007).

The present study compared psychophysical functions relating perceived intensity to concentration from previous experiments (that employed the sip-and-spit and dorsal flow stimulus delivery techniques) to functions observed with SSDT in the present study, to determine whether the SSDT would generate slopes for psychophysical functions similar to those generated in previous psychophysical experiments. We hypothesized that solutions delivered with SSDT would be perceived as less intense than those delivered with the sip-and-spit technique, and that the sip-and-spit technique would overestimate the slopes of intensity functions relating perceived intensity to concentration found with SSDT. We further hypothesized that the slopes of intensity functions relating perceived intensity to concentration reported in previous dorsal flow literature would more accurately predict the slopes of intensity functions obtained with the SSDT. Another objective was to investigate the response function for various taste stimuli in order to identify specific concentrations that would be optimal for future fMRI experiments.

## METHOD

### Participants

Twenty healthy young adults (10 females) from 18 to 29 years of age ($M$ = 22.65, $SD$ = 2.942) participated in the study after giving informed consent. The Institutional Review Board at San Diego State University approved the study for the use of human participants, each of whom was screened for ageusia and anosmia with taste threshold and odor threshold tests, respectively (Cain, Gent, Catalanotto, & Goodspeed, 1983, modified as in Murphy, Gilmore, Seery, Salmon, & Lasker, 1990), within 1 week of psychophysical testing. Additional exclusionary criteria consisted of upper respiratory infections or allergies within the prior 2 weeks.

### Procedure

The participants were presented with 27 aqueous solutions consisting of nine different stimuli each in three different concentrations and were asked to rate the intensity of each stimulus. To rate intensity, the participants used the Labeled Magnitude Scale (LMS; Bartoshuk et al., 2004; Green et al., 1996; Green, Shaffer, & Gilmore, 1993). Intensity was compared with the "strongest imaginable" taste. The participants were asked to rate the intensity of each stimulus relative to all other tastes that they had experienced.

The stimuli were presented in random order, at room temperature, as 0.3 ml, with a 3-ml, sterile, plastic syringe. The amount of solution given to the participant was equal to the amount delivered in prior fMRI experiments during one stimulation period (Cerf-Ducastel & Murphy, 2001; Haase et al., 2007). Before the stimulus presentation began, the participant rinsed the mouth thoroughly with distilled water for 10 sec and expectorated into a cup. The participant was then instructed to place the plastic syringe, filled with 0.3 ml of stimulus, approximately 0.5 cm behind the tip of the tongue, allowing the stimulus to flow over and around the edges of the tongue and be swallowed. Between stimuli, the participant rinsed the mouth with distilled water. Each stimulus was separated by at least 30 sec to minimize adaptation (Bartoshuk, McBurney, & Pfaffmann, 1964; McBurney et al., 1967).

### Stimuli

The following stimuli were presented in aqueous solutions: sucrose (0.16, 0.32, and 0.64 M), saccharin (0.007, 0.01, and 0.028 M), aspartame (0.001, 0.002, and 0.004 M), quinine (0.001, 0.0033, and 0.01 M), caffeine (0.01, 0.02, and 0.04 M), NaCl (0.08, 0.16, and 0.32 M), citric acid (0.01, 0.02, and 0.04 M), monosodium glutamate (MSG; 0.001, 0.005, and 0.025 M), and guanosine 5′-monophosphate (GMP; 0.001, 0.005, and 0.025 M).

### Data Analysis

The present experiment represents a $9 \times 3 \times 2$ mixed design with stimulus and concentration as within-groups variables and gender as a between-groups variable. A MANOVA was conducted with stimulus, concentration, and gender as the independent variables and perceived intensity scores as the dependent variable. One-sample $t$ tests were run to compare the slopes of perceived intensity in response to concentration found in the present study with the slopes of perceived intensity from previous literature, where dorsal flow and sip-and-spit techniques were employed (Table 1).

In the present study, comparisons were made with only those studies in the literature that (1) reported slopes of perceived intensity to concentration using magnitude estimation, (2) presented

**Table 1**
**Slopes of Psychophysical Functions for Taste Stimuli Obtained With Different Stimulus Delivery Techniques**

| | Stimulus Delivery Technique | | | | | |
|---|---|---|---|---|---|---|
| | SSDT | Sip-and-Spit | | Dorsal Flow | | |
| Stimulus | Slope | Slope | *p* | Slope | *p* | Area (mm$^2$) |
| Sucrose | 0.72 | 1.30 | **.17**[a] | 0.67 | **.90**[c] | |
| | | 1.67 | .03[b] | 0.75 | **.94**[b] | |
| | | | | 0.93 | **.61**[d] | |
| MSG | 0.72 | 0.31 | **.11**[e] | | | |
| | | 0.61 | **.67**[f] | | | |
| GMP | 0.42 | 0.71 | **.15**[f] | | | |
| Caffeine | 1.33 | | | 0.62 | **.20**[b] | |
| NaCl | 0.38 | 1.30 | <.01[a] | 0.54 | **.08**[g] | 126 |
| | | | | 0.47 | **.29**[g] | 40 |
| | | | | 0.50 | **.17**[g] | 12.6 |
| | | | | 0.45 | **.40**[g] | 4 |
| | | | | 0.43 | **.54**[c] | |
| | | | | 0.91 | <.01[d] | |
| QHCl | 0.14 | 1.00 | <.01[a] | 0.24 | <.01[g] | 126 |
| | | | | 0.32 | <.01[g] | 40 |
| | | | | 0.33 | <.01[g] | 12.6 |
| | | | | 0.30 | <.01[g] | 4 |
| | | | | 0.32 | <.01[c] | |
| | | | | 0.60 | <.01[b] | |
| | | | | 0.85 | <.01[d] | |
| Citric acid | 0.32 | | | 0.50 | .03[g] | 126 |
| | | | | 0.48 | **.05**[g] | 40 |
| | | | | 0.45 | **.10**[g] | 12.6 |
| | | | | 0.45 | **.10**[g] | 4 |
| | | | | 0.57 | <.01[b] | |
| Saccharin | 0.10 | 0.30 | .03[h] | 0.16 | **.50**[g] | 126 |
| | | | | 0.16 | **.50**[g] | 40 |
| | | | | 0.17 | **.43**[g] | 12.6 |
| | | | | 0.14 | **.65**[g] | 4.6 |

Note—Slope values represent the relationship between the perceived intensity of a stimulus and its concentration. Bold *p* values equal those from slopes generated using SSDT. SSDT, simulated scanning delivery technique; MSG, monosodium glutamate; GMP, guanosine 5′-monophosphate; NaCl, sodium chloride; QHCl, quinine hydrochloride. [a]Stevens, 1969. [b]Bartoshuk & Cleveland, 1977. [c]Bartoshuk, 1975. [d]Meiselman, Bose, & Nykvist, 1972. [e]Schiffman & Clark, 1980. [f]Rifkin & Bartoshuk, 1980. [g]Smith, 1971. [h]Moskowitz, 1970.

stimuli that were dissolved in water (not dissolved in flavored beverages or in food), and (3) presented pure tastants and not mixtures. In order to compare results from the present study with those in the published literature, geometric means of the perceived intensity for each gustatory stimulus were graphed on log-log plots. To find the slope of the function relating perceived intensity to concentration, linear regressions were run for each stimulus by taking the logs of perceived intensity and plotting them against the logs of the stimulus concentration. This method was chosen so that all slopes could be compared with those from the previous literature on the same scale.

## RESULTS

Psychophysical screening demonstrated that the participants had normal functioning for taste ($M = 0.00884$, $SE = 0.0042$) and olfactory (left nostril, $M = 7.1$, $SE = 0.347$; right nostril, $M = 6.9$, $SE = 0.343$) thresholds.

As expected, there was a main effect of stimulus [$F(8,144) = 35.42$, $p < .001$]. A Newman–Keuls multiple range test demonstrated that MSG, GMP, and caffeine were perceived as less intense ($p < .05$) than saccharin, NaCl, citric acid, and quinine. Sucrose was perceived as significantly less intense ($p < .05$) than NaCl, citric acid, and quinine. Saccharin was significantly less intense ($p < .05$) than citric acid and quinine. Also, NaCl was perceived as less intense ($p < .05$) than quinine. There was a main effect of concentration [$F(2,36) = 38.85$, $p < .001$]. A Newman–Keuls multiple range test indicated that the first of three concentrations was perceived as less intense than the second and third ($p < .05$). Similarly, the second concentration was perceived as less intense than the third ($p < .05$). There was no main effect of gender [$F(1) = 0.57$, $p = .46$]. There were no significant interactions for stimulus × concentration [$F(16) = 1.63$, $p = .06$], stimulus × gender [$F(8) = 1.20$, $p = .31$], or concentration × gender [$F(2) = 0.64$, $p = .54$].

Overall, comparisons of slopes of intensity functions for sucrose, NaCl, citric acid, saccharin, caffeine, and quinine in the present study indicate that using the SSDT resulted in slopes of intensity functions that were more similar to those found with the dorsal flow technique than to those found with the sip-and-spit technique (Table 1).

The slope of the psychophysical function relating perceived intensity to stimulus concentration for sucrose was not significantly different from the slopes of perceived intensity in previous studies that had employed the dorsal flow technique (Bartoshuk, 1975; Bartoshuk & Cleveland, 1977; Meiselman, 1971) and was not significantly different from those in one of two sip-and-spit experiments (Stevens, 1969; Table 1, Figure 1). However, the slope for sucrose was significantly lower than the slopes for sucrose generated by the sip-and-spit technique and reported by

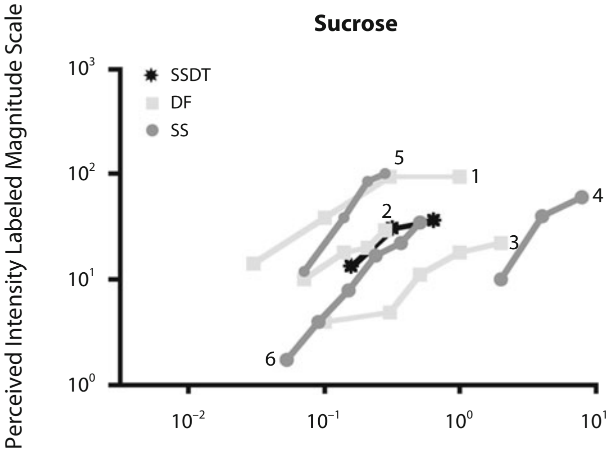


**Figure 1. Slopes of functions relating perceived intensity to concentration for sucrose. The black line represents the slope associated with the simulated stimulus delivery technique (SSDT) used in the present study. The numbered light gray lines represent the slopes associated with the dorsal flow delivery technique (DF) used in (1) Bartoshuk, 1975; (2) Bartoshuk and Cleveland, 1977; and (3) Meiselman, 1971. The numbered dark gray lines represent the slopes associated with the sip-and-spit delivery technique (SS) used in (4) Moskowitz, 1970; (5 and 6) Bartoshuk and Cleveland, 1977; and (6) Stevens, 1969. The slopes from the previous studies were estimated and graphed.**

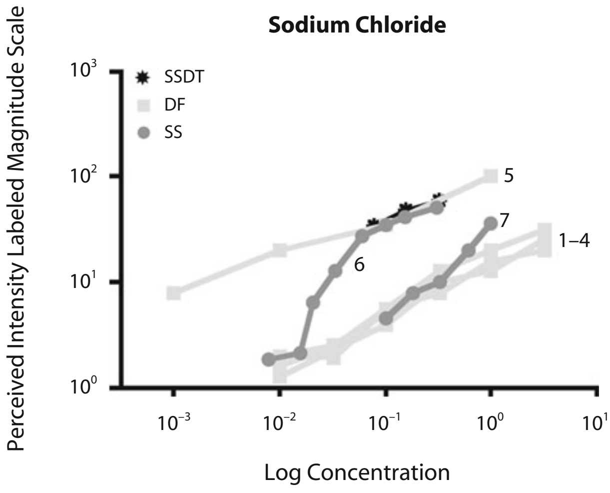


**Figure 2. Slopes of functions relating perceived intensity to concentration and area of stimulus application for sodium chloride. The black line represents the slope associated with the simulated stimulus delivery technique (SSDT) used in the present study. The numbered light gray lines represent the slopes associated with the dorsal flow delivery technique (DF) used in (1) Smith, 1971, 166 mm²; (2) Smith, 1971, 40 mm²; (3) Smith, 1971, 12.6 mm²; (4) Smith, 1971, 4 mm²; and (5) Bartoshuk and Cleveland, 1977. The numbered dark gray lines represent the slopes associated with the sip-and-spit delivery technique (SS) used in (6) Stevens, 1969; and (7) Meiselman, 1971. The slopes from the previous studies were estimated and graphed.**

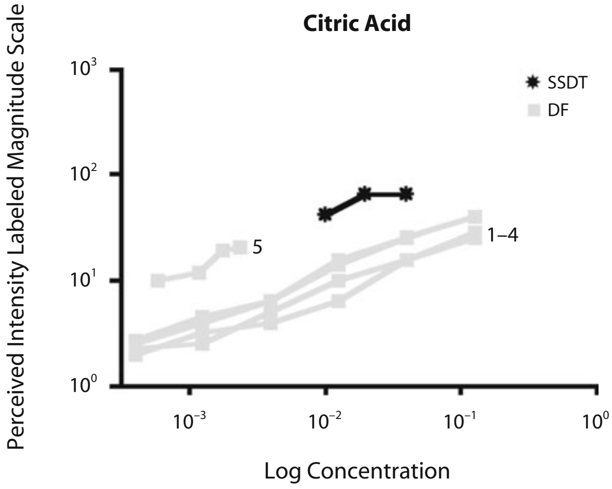


**Figure 3. Slopes of functions relating perceived intensity to concentration and area of stimulus application for citric acid. The black line represents the slope associated with the simulated stimulus delivery technique (SSDT) used in the present study. The numbered light gray lines represent the slopes associated with the dorsal flow delivery technique (DF) used in (1) Smith, 1971, 166 mm²; (2) Smith, 1971, 40 mm²; (3) Smith, 1971, 12.6 mm²; (4) Smith, 1971, 4 mm²; and (5) Bartoshuk and Cleveland, 1977. The slopes from the previous studies were estimated and graphed.**

Bartoshuk and Cleveland (1977). The slope of perceived intensity for NaCl was not significantly different from slopes reported in the majority of dorsal flow studies (Bartoshuk, 1975; Smith, 1971). However, the slope of perceived intensity for NaCl found in the present study using SSDT was significantly lower than the slope for perceived intensity generated by the dorsal flow technique (Meiselman, 1971), and it was lower than the slope reported in a previous study using the sip-and-spit technique (Stevens, 1969; Table 1, Figure 2). The slope of perceived intensity generated using the SSDT technique for citric acid was not significantly different from the slope of the intensity function for citric acid generated by the dorsal flow technique and reported by Smith; however, the slope for citric acid was significantly different from those generated by the dorsal technique and reported by Bartoshuk and Cleveland (1977; Table 1, Figure 3). The slope of the function for perceived intensity of saccharin in the present study was not significantly different from the slope generated by the dorsal flow technique and reported by Smith, but it was significantly different from the slope generated by the sip-and-spit technique and reported by Moskowitz (1970; Table 1, Figure 4). The slope of the intensity function for QHCl was significantly different from the slope generated by the dorsal flow technique (Bartoshuk, 1975; Bartoshuk & Cleveland, 1977; Meiselman, 1971; Smith, 1971) and by the sip-and-spit technique (Stevens, 1969; Table 1, Figure 5). Additionally, the slope for caffeine was not significantly different from that generated by the dorsal flow technique and reported by Bartoshuk (1979; Table 1, Figure 6).

The slope of the intensity function for GMP was not significantly different from the slope generated using the sip-and-spit technique and reported by Rifkin and Bartoshuk

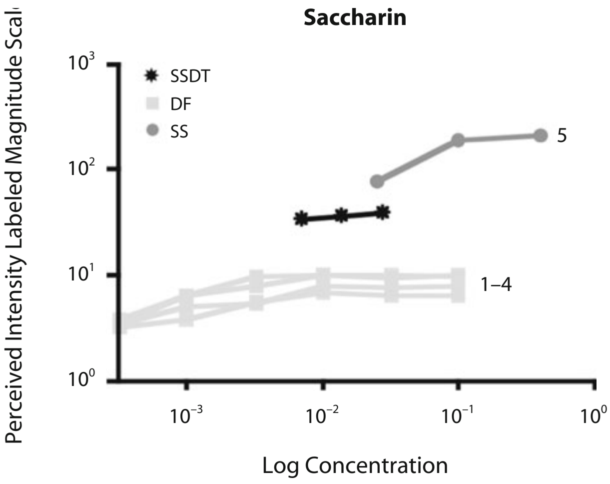


**Figure 4. Slopes of functions relating perceived intensity to concentration and area of stimulus application for saccharin. The black line represents the slope associated with the simulated stimulus delivery technique (SSDT) used in the present study. The numbered light gray lines represent the slopes associated with the dorsal flow delivery technique (DF) used in (1) Smith, 1971, 166 mm²; (2) Smith, 1971, 40 mm²; (3) Smith, 1971, 12.6 mm²; and (4) Smith, 1971, 4 mm². The numbered dark gray line represents the slope associated with the sip-and-spit delivery technique (SS) used in (5) Moscowitz, 1970. The slopes from the previous studies were estimated and graphed.**

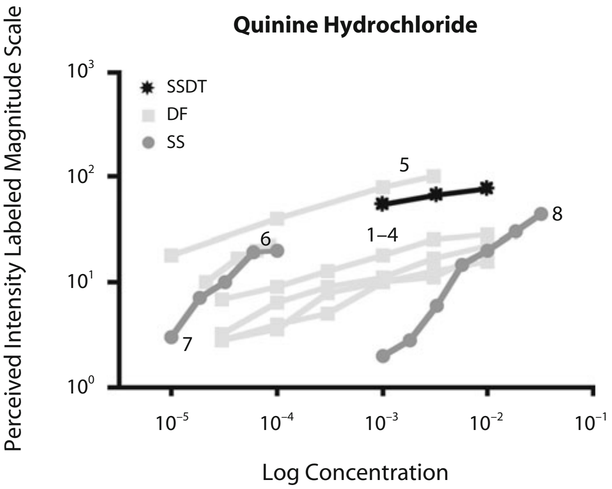


**Figure 5. Slopes of functions relating perceived intensity to concentration and area of stimulus application for quinine hydrochloride. The black line represents the slope associated with the simulated stimulus delivery technique (SSDT) used in the present study. The numbered light gray lines represent the slopes associated with the dorsal flow delivery technique (DF) used in (1) Smith, 1971, 166 mm²; (2) Smith, 1971, 40 mm²; (3) Smith, 1971, 12.6 mm²; (4) Smith, 1971, 4 mm²; (5) Bartoshuk, 1975; and (6) Bartoshuk and Cleveland, 1977. The numbered dark gray lines represent the slopes associated with the sip-and-spit delivery technique (SS) used in (7) Meiselman, 1971; and (8) Stevens, 1969. The slopes from the previous studies were estimated and graphed.**

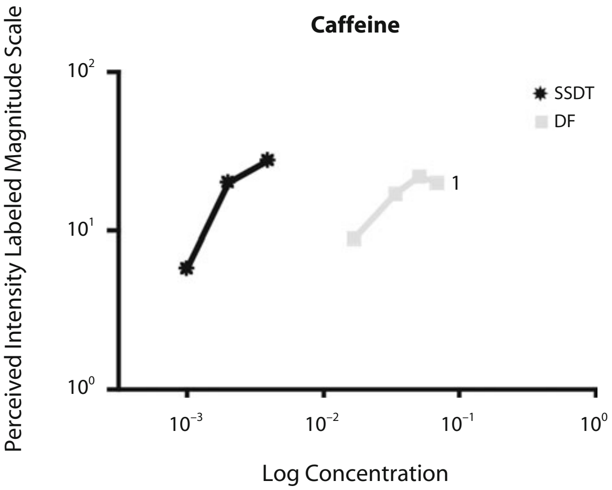


**Figure 6. Slopes of functions relating perceived intensity to concentration and area of stimulus application for caffeine. The black line represents the slope associated with the simulated stimulus delivery technique (SSDT) used in the present study. The numbered light gray line represents the slope associated with the dorsal flow delivery technique (DF) used in (1) Bartoshuk and Cleveland, 1977. The slope from the previous study was estimated and graphed.**

(1980; Table 1). The slope for MSG was not significantly different from the slopes generated elsewhere by the sip-and-spit technique (Rifkin & Bartoshuk, 1980; Schiffman & Clark, 1980; Table 1, Figure 7). To our knowledge, no information was available regarding the slope of the perceived intensity functions for MSG and GMP using the dorsal flow procedure.

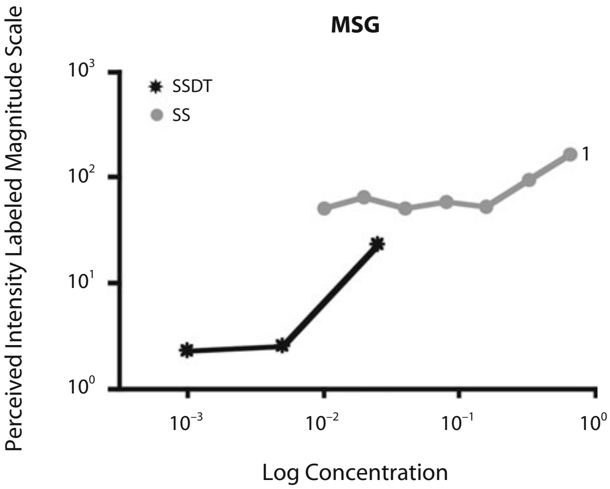


**Figure 7. Slopes of functions relating perceived intensity to concentration and area of stimulus application for MSG. The black line represents the slope associated with the simulated stimulus delivery technique (SSDT) used in the present study. The numbered dark gray line represents the slope associated with the sip-and-spit delivery technique (SS) used in (1) Schiffman, 1980. The slope from the previous study was estimated and graphed.**

## DISCUSSION

The objective of the present study was to examine the differences in the slopes of the psychophysical functions relating perceived intensity to concentration for taste stimuli generated by typical psychophysical stimulus delivery techniques and by a stimulus delivery technique that mimicked critical features of one utilized within the fMRI scanner (i.e., SSDT). The results showed that the slopes of psychophysical functions generated using the SSDT were more similar to those generated by dorsal flow stimulation than to those generated by sip-and-spit stimulation (Figures 1–7). This finding is not inconsistent with Meiselman's (1971) results, which showed differences between the intensity functions generated with the sip-and-spit technique and those generated with the dorsal flow technique.

The present findings are particularly important for the design and implementation of gustatory stimulus delivery techniques in the fMRI environment. As observed in the present study, employing a stimulus delivery technique adapted to the confines of fMRI may produce perceived intensity functions for taste stimuli that differ from perceived intensity functions generated using whole-mouth sip-and-spit stimulation in typical behavioral experiments. The observed differences may have resulted from differences in the amount of stimulus delivered in fMRI experiments. Because fMRI image quality can be compromised by the significant head movement caused by the swallowing of large quantities of liquid, the amount of stimulus delivered in the fMRI environment may be limited to amounts in the range of 0.3 ml per bolus, whereas in sip-and-spit experiments, the amount of liquid in each sample is more typically 5–10 ml. Previous research has demonstrated that the stimulated area of the tongue affects taste perception (Miller, 1986; Zuniga et al., 1993). Further, differences in perceived intensity are associated with the number of taste buds that are stimulated (Miller & Reedy, 1990; Zuniga et al., 1993), and taste bud density varies, increasing as much as five-fold from the anterior region to the midregion of the tongue (Miller, 1986). Collings (1974) reported that the slope of perceived intensity varies with the stimulus and the area of stimulation. For example, slopes for quinine were found to be steeper on the vallate papillae than on the fungiform papillae (Collings, 1974). Thus, the area and the region of the tongue and oral cavity stimulated are important factors in psychophysical response (Miller, 1988), and to the extent that restricting the amount of stimulus delivered affects the regions of the oral cavity and tongue that are stimulated, this may be an important consideration in the fMRI environment.

In the present study, saccharin and quinine had high perceived intensities, with lower slopes of intensity functions than those previously reported in the literature for sip-and-spit and dorsal flow delivery techniques. The slopes of functions relating perceived intensity to concentration for quinine and saccharin may have been influenced by a number of factors: saturation, the high concentrations used, and limitations in the range of concentrations. Quinine is a bitter stimulus, and saccharin is an artificial sweetener; however, at high concentrations, saccharin is known to produce a bitter taste (Bartoshuk, 1979; Schiffman, Booth, Losee, Pecore, & Warwick, 1995; Schiffman et al., 1994). Specifically, the bitterness function for saccharin grows at a lower rate than the perceived intensity function for sucrose; it then decreases and plateaus as concentration increases (Moskowitz, 1970). Moskowitz concluded that this phenomenon results from the increase in bitterness and decrease in sweetness associated with high concentrations of saccharin. Thus, in the present study, the concentration series used for saccharin may have been high enough to produce substantial bitterness, resulting in a shallow slope relating perceived intensity to concentration, similar to that of quinine.

We limited comparisons of the present data only to data from studies that used magnitude estimation (Marks, 1974; Stevens, 1969) for rating intensity (Bartoshuk, 1975; Bartoshuk & Cleveland, 1977; Meiselman, 1971; Moskowitz, 1970; Rifkin & Bartoshuk, 1980; Smith, 1971; Stevens, 1969); we did not include studies that used other scaling methods, such as category scales. The psychophysical functions produced using the LMS have been shown to be equivalent to those produced using magnitude estimation in response to oral sensation (taste, temperature, and pain; Green et al., 1993) and gustatory and olfactory stimuli (Green et al., 1996). Future studies might address whether data from other scaling methods, such as category scales, produce similar results.

Finally, fMRI studies of gustatory function require presentation of the stimuli within a scanning environment where other aspects of stimulus delivery and behavioral performance (controlling taste stimuli by computer in event-related designs, delivering liquid inside the magnet, swallowing while supine, moving of the head, and producing and recording online psychophysical assessments during fMRI scans) must be taken into account. We and others have addressed these issues elsewhere, and the interested reader is referred to those studies for further information (Haase et al., 2007; Haase et al., 2009; Stice et al., 2008).

In conclusion, the present study showed that the SSDT produced psychophysical functions with slopes that were generally lower than those reported in the literature from experiments conducted with the sip-and-spit technique. In contrast, the SSDT produced psychophysical functions that were similar to slopes of intensity functions reported in the literature for experiments conducted with the dorsal flow procedure. It may be particularly useful to choose stimuli and stimulus concentrations for taste fMRI studies on the basis of behavioral data collected with a stimulus amount and stimulation technique that mimics the stimulus delivery used inside the scanner. The unique requirements of stimulus delivery within the scanning environment require an understanding of the interdependent associations among stimulus quality, concentration, stimulus amount, and stimulus delivery technique to ensure that perceptions of the stimuli can be appropriately interpreted. More broadly, precise psychophysical experimentation in conjunction with fMRI studies is necessary for properly interpreting the observed associations among brain activation, perception, and cognition.

## AUTHOR NOTE

This study was funded by NIH Grant AG04085 to C.M. We thank Paul Gilbert for comments on the manuscript, as well as Aaron Jacobson and Craig Mellinger for their assistance in data collection. Correspondence concerning this article should be addressed to C. Murphy, SDSU–UCSD Joint Doctoral Program in Clinical Psychology, 6363 Alvarado Ct., Ste. 101, San Diego, CA 92120-4913 (e-mail: cmurphy@sciences.sdsu.edu).

*Note—Accepted by the previous editorial team, when Thomas H. Carr was Editor.*

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(Manuscript received May 7, 2007;
revision accepted for publication February 20, 2009.)