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Contextual Effects in Judgments of Taste Intensity: No Assimilation, Sometimes Contrast

Timothy G. Shepard,

John B. Pierce Laboratory, New Haven, CT, USA; College of Optometry, The Ohio State University, Columbus, OH, USA

Adam Y. Shavit,

John B. Pierce Laboratory, New Haven, CT, USA; Hunter College, New York, NY, USA

Maria G. Veldhuizen, and

John B. Pierce Laboratory, New Haven, CT 06519, USA; Department of Psychiatry, Yale University School of Medicine, New Haven, CT, USA

Lawrence E. Marks

John B. Pierce Laboratory, New Haven, CT, USA; School of Public Health and Department of Psychology, Yale University, New Haven, CT, USA

Abstract

Judgments of taste intensity often show contextual contrast but not assimilation, even though both effects of stimulus context appear in other sense modalities, such as hearing. Four experiments used a paradigm that shifts the stimulus context within a test session in order to seek evidence of assimilation in judgments of the taste intensity of sucrose and, for comparison, the loudness of 500-Hz tones. Experiment 1 found no assimilation in taste using three response scales, magnitude estimation, labeled magnitude, and visual analog, but did find evidence of contrast. Experiments 2 and 3 found no clear evidence of either assimilation or contrast in taste, but found consistent evidence of assimilation in loudness. Experiment 4 found no assimilation in loudness, however, when the intervals between successive stimuli increased from about 6 to 30 s in order to match the interval used with sucrose in Experiments 1–3. Taken together, these findings suggest that the assimilation found in intensity judgments in other sensory modalities may not appear in taste perception because of the slower rates presenting of taste stimuli.

Keywords

taste; loudness; intensity; context; contrast; assimilation

Corresponding author: Lawrence E. Marks, John B. Pierce Laboratory, 290 Congress Avenue New Haven, CT 06519, USA, marks@jbpierce.org.

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Introduction

Perceptual judgments can vary substantially with changes in stimulus context. For practical and historical reasons, research on contextual effects has focused largely on perceived intensity. Perhaps the best-known contextual effect in judgments of intensity is *contrast*, the tendency to judge a test stimulus as weaker in the context of more intense stimuli, stronger in the context of less intense stimuli. In hearing, for example, tones are judged softer in contexts containing more sounds at high levels, louder in contexts containing more sounds at low levels (Melamed & Thurlow, 1971). Similarly, in taste, 0.3 M sucrose, for example, is rated as stronger in perceived intensity when the concentrations of the other sucrose stimuli mostly fall below 0.3 M, but as weaker when the other concentrations mostly exceed it (Riskey, Parducci, & Beauchamp, 1979; see also Riskey, 1982; Lawless, Horne, & Spiers, 2000; Schifferstein & Frijters, 1992; Schifferstein & Oudejans, 1996; Marks, Shepard, Burger, & Chakwin, 2012; Hallowell, Parikh, Veldhuizen, & Marks, 2016).

Contrast has a complement, called *assimilation*: the tendency to judge a test stimulus as stronger following more intense stimulation, weaker following less intense stimulation. In an extensive series of experiments in hearing and vision, Ward (1979, 1985, 1986, 1990) showed how contrast and assimilation may both operate at the same time on a trial-by-trial basis, with the response to the current stimulus *contrasting* with the *stimulus* on the previous trial but *assimilating* to the *response* (rather than the stimulus) on the previous trial. In addition to their opposing directions, there is an important difference, however, between trial-by-trial contrast and assimilation: Assimilation depends on prior responses, regardless of the physical properties of stimuli that produce the responses, even if the previous and current stimuli are delivered to different sensory modalities (e.g., Ward, 1985). Contrast, on the other hand, depends not only on the intensity of the previous stimulus, but also on its physical properties relative to those of the current stimulus – in loudness perception, for instance, on whether the stimuli have the same acoustic frequency (Ward, 1990).

Earlier experiments extended these findings to the chemical senses by using a dual-context paradigm in which two different stimuli take on complementary sets of concentrations in different contextual conditions (Rankin & Marks, 1991, 2000). Consider the following example, using the taste stimuli NaCl and sucrose. In condition A, the concentrations of NaCl were relatively low whereas those of sucrose were relatively high, whereas in condition B, the relative concentrations switched, those of NaCl being high and those of sucrose low. Subsets of concentration of each taste stimulus were common to the two contextual conditions. The results – the judgments given to the common stimuli – showed stimulus-specific contrast, with the perceived intensity of NaCl being greater in condition A than B and the perceived intensity of sucrose being greater in B than A (Rankin & Marks, 1991). These results are consistent with the view that structurally and perceptually different stimuli of the same modality can induce stimulus-specific contrast effects – these effects being evident in paradigms in which assimilation effects are neutralized when the stimulus sets produce similar overall ranges of perceived intensity in the two contextual conditions. Rankin and Marks also found, not surprisingly, that the magnitude of these stimulus-specific contrast effects diminished when the two stimuli were NaCl and a mixture of NaCl + sucrose rather than pure NaCl and pure sucrose. Presumably, the reduction in the magnitude

of the contrast effect reflected a greater overlap of the contexts induced by NaCl and the mixture, which also contained NaCl.

A subsequent study (Rankin & Marks, 2000) expanded these findings by showing substantial contextual contrast effects in dual-context paradigms in which the test stimuli were, for example, sucrose and vanillin, sucrose being a gustatory flavorant and vanillin an olfactory flavorant. Across seven experiments, Rankin and Marks found that variations in stimulus context produced stimulus-specific contrast when the stimuli were compositionally different (e.g., sucrose versus NaCl, orange, or vanillin) but not when they were the same (e.g., vanillin presented orally versus nasally). Perceived dissimilarity across stimuli, assessed in a separate experiment, could not account for the variations in the magnitude of the contrast effect, suggesting instead that the contrast effects mainly reflect the outcome of stimulus-specific, adaptation-like processes. Importantly, the dual-context paradigm used by Rankin and Marks (1991, 2000) held the overall range of stimuli, and hence of responses, roughly equal across contextual conditions, thereby keeping constant the processes – presumably, decisional or response based – that produce assimilation, and hence minimize or eliminate it.

Although, as just described, the use of dual-context paradigms can help to minimize or eliminate assimilation effects, leaving contrast effects open to investigation, it is not clear whether or how we might minimize or eliminate contrast effects in order to isolate and measure assimilation. When the intensity of a prior stimulus is greater (or smaller) than the intensity of the current stimulus, both assimilation and contrast may occur, and the net effect will presumably represent their combination. Consequently, the approach taken here was to apply to judgments of taste intensity a paradigm in which this net effect is likely to favor assimilation over contrast. Research on taste intensity includes several reports of contextual contrast, as cited earlier, but few if any of clear assimilation (for a report of sequential assimilation in hedonic judgments in taste, see Schifferstein and Kuiper (1997). In other sensory systems, however, such as hearing, assimilation is as prevalent as contrast, and often surpasses it in magnitude.

Marks (1993, Experiments 3–8) used a shifting-context paradigm to study how stimulus context affects judgments of loudness of 500-Hz tones. Over the course of a single test session, the set of dB levels of the tones shifted abruptly and repeatedly up and down, with a subset of dB levels common to the low and high sets. The predominant effect was assimilation: The common stimuli were judged to be louder in the local context of higher dB levels, softer in the local context of lower dB levels – presumably, the outcome of strong assimilation that was offset only partially by weaker contrast. Experiments 10–14 within the same study shifted between a set of tones at 500 Hz having low sound pressure levels (SPLs) plus tones at 2500 Hz having high SPLs and another set of tones at 500 Hz having high SPLs plus tones at 2500 Hz having low SPLs (a within-session version of the dual-context paradigm described above). Like the between-session version, the within-session version neutralizes the (non-specific) assimilation by holding the overall range of loudness constant across the contextual sets, thereby revealing the presence of residual contrast that is specific to each sound frequency.

A predominance of assimilation over contrast is evident in several sensory modalities, including vision as well as hearing (Ward, 1979, 1982, 1985) and in several behavioral tasks, including stimulus identification (e.g. Stewart, Brown, & Chater, 2005; Ward & Lockhead, 1971). The latter is noteworthy as it indicates how context can interact with stimulus information that may be ecologically important. Given these findings, the absence to date of clear evidence of assimilation in judgments of taste intensity is striking, and it motivates the current investigation.

The present experiments used Marks's (1993) shifting-context paradigm, shown effective in revealing assimilation in loudness, to ask how within-session changes in stimulus context affect the perceived taste intensity of sucrose. To start, we note that Marks's experiments on loudness all used the method of magnitude estimation, and Ward (1985) has shown similar patterns of assimilation and contrast in hearing and vision with magnitude-estimation scales and category-rating scales. Nevertheless, the psychophysical method might matter: Ward has shown that assimilation depends on responses to prior (contextual) stimuli, rather than the physical intensities of the stimuli, so assimilation might vary with response scale. Lawless et al. (2000) found that the contrast obtained in judgments of the sweetness of sucrose varied in magnitude with the scale used for judgment: Contrast was greatest with a 15-point category scale, somewhat smaller with a labeled-magnitude scale, and smallest with a magnitude-estimation scale. Consequently, Experiment 1 compared the way that shifting stimulus context affected the perception of sucrose when the same participants, in different test sessions, judged taste intensity on a magnitude-estimation scale (MES), a labeled-magnitude scale (LMS), and a visual-analog scale (VAS).

Experiment 1

Experiment 1 applied the shifting-context method previously used with loudness of a single sound frequency (Marks, 1993, Experiments 3–8). Here, within a given test session, participants judged the taste intensity of several concentrations of sucrose, using, in different sessions, an MES, LMS, or VAS. Over the course of each session, the set of sucrose concentrations switched back and forth between low and high, with a subset of concentrations common to both sets. Marks's dynamic, shifting-context design led to consistent assimilation in loudness: Tones with intensities common to the two contextual sets were judged softer in the low set, louder in the high set. Experiment 1 asked whether judgments of taste intensity would show a similar assimilation using each of three response scales.

Materials and method

Ethics statement—Procedures for this and subsequent experiments were approved by the Human Subjects Committee of Yale University, in accord with the 1964 Declaration of Helsinki. Before taking part in any experiment, each participant provided written informed consent. Participants were informed that they were free to withdraw from any experiment at any time and that their data would be kept confidential.

Participants—The 24 participants (9 men and 15 women) ranged from 18 to 32 years old (mean = 24.0, sd = 3.9) and were paid \$10 per hour. Most participants came from the Yale

University community, and none reported any taste impairment. Participants were asked to refrain from eating or drinking anything except water one hour prior to the experiment. Research in this and all subsequent experiments complied with the Declaration of Helsinki for Medical Research Involving Human Subjects, and all participants gave written informed consent under protocols approved by Yale University's Human Subjects Committee.

Stimuli—The stimulus was sucrose (J.T. Baker, CAS#57-50-1 C₁₂H₂₂O₁₁), dissolved in deionized water to 10 concentrations, from 0.00476 to 0.3 M in steps of 0.2 log unit. The low set contained the 7 lowest concentrations, 0.00476–0.0754 M, and the high set contained the 7 highest, 0.0189–0.3 M. Four concentrations were common to both conditions.

Design—Each participant served in 3 sessions, held on separate days, using a different scale in each session. With 3 scales, there are 6 possible orders, and the order of the scales across sessions was counterbalanced over the participants so that unique subgroups of 4 participants received each of the 6 orders. Contextual sets were also counterbalanced so that, with each scale, 12 participants began the session with the high set and 12 participants began with the low set.

A single block, high (H) or low (L), contained 7 trials, and each session contained 8 blocks, either L-L-H-H-L-L-H-H or H-H-L-L-H-H-L-L. Thus, the stimulus concentrations switched seamlessly from low to high or high to low after every 14 trials (2 blocks); the participants were not informed that the concentrations would shift.

Procedure

Each session began with instructions to the participants. With the MES, participants were asked to rate the sweetness intensity of each stimulus numerically. On the first trial, the participants selected whatever number they deemed appropriate to represent the taste intensity; on subsequent trials, the participants assigned other numbers in proportion (e.g. Marks, 1993). Participants entered the numerical responses (whole numbers, decimals) directly on a keyboard. With the LMS, the participants viewed, on a computer monitor, a vertical LMS with descriptive labels ranging from 'barely detectable,' just above the scale's lower end, to 'strongest imaginable,' at the upper end (Green, Shaffer, & Gilmore, 1993); on each trial, the participants moved a cursor to the appropriate location on the scale, then clicked the mouse. With the VAS, participants viewed a horizontal line anchored on the left and right, respectively, by the labels 'extremely weak' and 'extremely strong,' moved the cursor to the appropriate location on the scale, then clicked the mouse.

On each trial, the participants sipped 5 ml of the stimulus solution (in a 30 ml disposable plastic cup), spit out the solution, and then rated the sweetness intensity on the scale used in that session, with the order of the stimuli randomized differently in each session (subsequent experiments used similar randomizations). Participants rinsed their mouth with deionized water before sampling the next stimulus, approximately 30 s later. Each session lasted about 30 min.

Data analysis

Analysis began with normalization of the data to transform each participant's overall mean on each scale to equal 10. To do so, we divided each participant's mean response to each stimulus by that participant's mean across stimuli and then multiplied the result by 10. This procedure is similar to ones used earlier (Marks et al., 2012; Hallowell et al., 2016, modified from the procedure of Lane, Catania, & Stevens, 1961). The aim of doing this is to reduce as far as possible any variability associated with the numerical representations of the different scales. Note that the scale units for the LMS and VAS are in any case arbitrary: as a matter of convenience, we counted number of pixels from the 0 end of the rating line, but we could just as easily have measured distance in mm or cm. Normalization minimizes the possibility of artificially inflating error terms or deviations from sphericity, assessed in the subsequent analysis of variance (ANOVA). We conducted the ANOVA on the within subjects variables of scale (MES, LMS, VAS), context (low, high), and concentration (4 concentrations common to the low and high contexts). When the ANOVA revealed non-sphericity in the results, as assessed by the method of Huynh and Feldt (1976), we reported the original values of *df* and the values of epsilon, as well as the corrected values of *p*.

Results and discussion

Figure 1 plots the average normalized ratings of sweet intensity using the MES, LMS, and VAS as functions of sucrose concentration. For each scale, the figure plots separately the ratings given to the stimuli in the low and high contexts. With each scale, stimulus context exerted a small but consistent contrast effect: A fixed concentration of sucrose was judged weaker when it appeared in the high set compared to the low set. On average, the ratings given to the 4 common stimuli were 10.3%, 9.3%, and 23.3% greater in the low context compared to the high context with the MES, LMS, and VAS, respectively (note that calculating percentages assumes that all 3 scales have meaningful zero points). The presence of contextual contrast received statistical support from the results of the ANOVA, which showed a significant main effect of context, $F(1,23) = 9.609$, $p = .005$. The absence of significant interaction between context and scale, $F(2,46) = 1.076$, $p = .31$ (epsilon = .932), is consistent with the inference that the contrast is largely comparable in magnitude with all 3 scales – although it's plausible that modest scale-related differences do exist.

As Figure 1 also shows, contrast, measured as a percentage, was more than twice as great at the higher sucrose concentrations than at the lower ones: Averaged over the 3 scales, contrast equaled 9.1%, 7.7%, 19.9%, and 20.6% with increasing concentration, and the interaction of context with concentration was significant, $F(3,69) = 3.821$, $p = .03$ (epsilon = .821). The only other significant term in the ANOVA was the main effect of concentration, $F(3,69) = 84.99$, $p < .001$ (epsilon = .671).

Experiment 2

The results of Experiment 1 showed that shifting between low and high stimulus contexts produced a modest overall contrast effect in judgments of perceived sweet intensity. Although this outcome is consistent with earlier findings on judgments of taste intensity (e.g., Rankin & Marks, 2000), it differs markedly from the findings previously reported with

a comparable experimental design on judgments of loudness. With an analogous design, loudness consistently showed assimilation rather than contrast (Marks, 1993). To follow up this difference between results and determine whether context affects judgments of taste intensity and loudness in different ways, Experiment 2 applied the shifting-context paradigm to both the taste intensity of sucrose and the loudness of 500-Hz tones, testing both modalities in different sessions on the same participants.

According to Helson's (1964) adaptation-level (AL) theory, ambient background stimulation can contribute to the AL, to which the perceiver compares the intensity of the test stimulus. Although AL theory is typically used to account for contrast rather than assimilation, the principles of AL may apply to assimilation too. If so, then it is plausible that intermittent background sounds (e.g. from electronic equipment, ventilation system, and outside traffic) sometimes audible in the gustatory test room might affect the judgments of taste as well as loudness. To reduce possible effects of ambient noise on the judgments, all test sessions in Experiment 2 (and subsequent experiments) were conducted, in both the taste and loudness conditions, in a sound-shielded chamber. Moreover, Experiment 2 (and subsequent experiments) used the method of magnitude estimation, previously shown effective in revealing contextual assimilation as well as contrast (Marks, 1993). Finally, given the relatively small inter-stimulus interval (ISI) between successive auditory trials, the number of auditory trials was increased to provide more data.

Materials and method

Experiment 2 resembled Experiment 1 in stimuli and design, except that Experiment 2 presented the stimuli in both the taste and loudness sessions in a sound-shielded room (Industrial Acoustics) and, in the loudness sessions, presented 16 blocks of trials rather than 8. For the taste measurements, the room was equipped with an *ersatz* sink, consisting of a funnel with tubing that led to a disposal container outside the chamber.

Participants—Twelve participants (3 men and 9 women) between 18 and 25 years (mean 21.8, $sd = 2.2$) were paid \$10 per hour to take part. Each participant served in two sessions, judging taste intensity in one session and loudness in the other, order of sessions again counterbalanced over the participants.

Stimuli—The taste stimuli consisted of sucrose dissolved in deionized water to 12 concentrations, from 0.00126 to 0.2 M in successive steps of 0.2 log unit. The low set contained the 8 lowest concentrations, 0.00126–0.0317 M, the high set the 8 highest, 0.00796–0.2 M. Again, 4 concentrations were common to the 2 sets.

The 12 auditory stimuli had the same frequency (500 Hz) and levels (35–90 dB, in steps of 5 dB) as those used by Marks (1993, Experiments 3–8). The 8 SPLs in the low set ranged from 35–70 dB and the 8 in the high set from 55–90 dB. Tones were produced by a Beltone Model 109 audiometer and presented binaurally for 0.25 s (versus 1 s in Marks, 1993) through calibrated TDH-49P headphones mounted in MX41/AR cushions. The difference between durations of 0.25 and 1 s is not consequential to loudness (e.g. Stevens & Hall, 1966).

Design—Each participant served in two sessions, one for taste and one for hearing, 6 participants starting with taste and 6 starting with hearing. Each taste session contained 8 consecutive blocks and each loudness session contained 16 consecutive blocks, with each block containing 8 trials of low (L) or high (H) stimulus levels. Thus, a session presented either L-L-H-H-L-L-H-H or H-H-L-L-H-H-L-L, so there were either 4 or 8 replicates of each contextual set in each condition for taste and for loudness, respectively. Again, set-to-set transitions were seamless, and participants were not told that contexts would shift.

Procedure—In taste sessions, on each trial, the participants sipped 5 ml of one of the stimuli and rated its perceived sweetness intensity on a magnitude-estimation scale (MES), rinsing before the next trial, which began after approximately 30 s. In auditory sessions, on each trial, the participants received 1 of the 8 SPLs from the set (low or high) and rated loudness on an MES. Each trial lasted about 6 s. Each session (taste and loudness) lasted about 30 min.

Results and discussion

We omitted the data of 1 participant who gave a judgment of 0 on every trial to 6 of the 12 possible concentrations of sucrose, not all of which were the lowest concentrations. Figure 2 gives the average results obtained from the remaining 11 participants. Omitting the data of the 1 participant removed a non-monotonicity that would otherwise be evident in the taste judgments in the high set, but left unchanged the general trends of the data: Taste shows assimilation at the 2 lowest common concentrations, changing to contrast at the 2 higher common concentrations (average across the 4 common stimuli = 10.9% assimilation). Loudness, however, shows assimilation at all 4 common concentrations (average = 24.8%).

An ANOVA conducted on the data of the 11 participants showed no significant main effect of context, pooled over modalities and contexts, $F(1,10) = 2.70$, $p = 0.13$, but did show a significant interaction of context, modality, and stimulus level, $F(3,30) = 3.94$, $p = .029$ (epsilon = .601). An ANOVA run on the taste judgments alone showed no significant main effect of context, $F(1,10) < 1$, but a significant interaction between context and sucrose concentration, $F(3,30) = 4.77$, $p = .031$ (epsilon = .516), consistent with the change from assimilation at the lower concentrations to contrast at the higher ones. A similar ANOVA on the loudness judgments, however, did show a significant effect of context, $F(1,10) = 11.6$, $p = .007$, consistent with the pervasive assimilation, but no significant interaction between context and sound level, $F(3,30) < 1$. In sum, the results of Experiment 2 hint at concentration-dependent effects of context in taste, perhaps different from the effect in loudness perception. But the results in taste are far from conclusive.

Experiment 3

Although the results of Experiment 2 hint at concentration-dependent effects of context in taste, in general, the overall results of the first 2 experiments are not clear-cut. Experiment 1 showed taste contrast and Experiment 2 showed assimilation at lower concentrations changing to contrast at higher concentrations. There is, however, a notable feature of the taste ratings in both experiments: These ratings suggest that the lowest concentrations of sucrose were barely discernible from water, as evident in the tendency for the taste functions

in Figures 1 and 2 to become asymptotic at the lowest concentrations. The responses obtained at the low concentrations raise the question whether the water rinses themselves might contribute to the context (especially as a rinse precedes each subsequent taste stimulus) (see Schifferstein & Kuiper, 1997). If the rinses do contribute to the contexts, however, they should contribute to both of them – presumably reducing high contexts more than low contexts. Moreover, the rinses might affect the magnitude of contrast but not of assimilation because participants do not judge the water rinses, and assimilation appears to depend on response magnitude rather than stimulus intensity (e.g. Ward, 1979, 1990). Implicit ratings of the intensity of the rinses seem unlikely.

All of the auditory stimuli, on the other hand, were clearly audible. Perhaps contextual effects in taste are more robust at higher stimulus concentrations. Consequently, Experiment 3 repeated Experiment 2 but used higher concentrations of sucrose.

Materials and method

Participants—Again, there were 12 participants (5 men and 7 women) between 19 and 33 years (mean 24.5, $sd = 4.9$), paid \$10 per hour. Each participant served in 2 sessions, judging taste intensity in 1 session and loudness in the other, their order counterbalanced over participants.

Stimuli and design—The design of Experiment 3 followed that of Experiment 2, except for a change in the sucrose concentrations, which now varied from 0.0178–0.796 M in steps of 0.15 log unit, the 8 concentrations in the low set ranging from 0.0178–0.2 M and the 8 in the high set ranging from 0.071–0.796 M. The auditory stimuli remained the same.

Results and discussion

The averages of the normalized magnitude estimates appear in Figure 3. The function for sucrose in the low-context condition is no longer asymptotic at low concentrations, as it was in Experiments 1 and 2. More important, the judgments of taste intensity now hint at contrast, whereas the judgments of loudness again show assimilation. The taste judgments were greater (28.6%, on average) when the sucrose concentrations were low rather than high, whereas the judgments of loudness were greater (26.8%, on average) when the SPLs were high rather than low.

In support of the conclusion that context affected taste judgments and loudness judgments differently is the significant interaction in ANOVA between context and modality, $F(1,11) = 6.054$, $p = .032$. The contrast effect in taste itself, however, is not itself significant, $F(1,11) = 1.521$, $p = .243$, although the assimilation effect in loudness is, $F(1,11) = 17.27$, $p = .002$.

Experiment 4

Taken together, the results of Experiments 1–3 provide no clear evidence that changing stimulus context produces assimilation in judgments of taste intensity. If anything, the results suggest a small, albeit evanescent, contrast in taste, strikingly unlike the consistent assimilation in the judgments of loudness, obtained in Experiments 2 and 3 using an analogous experimental paradigm and, in each experiment, the same participants as those

who judged taste. Two alternative scenarios suggest themselves. One says that assimilation is simply absent from judgments of taste intensity. The other says that both assimilation and contrast characterize taste judgments, as they do loudness (e.g., Ward, 1990), but that, under the present conditions, assimilation and contrast in taste were roughly comparable in magnitude, with contrast perhaps on the whole slightly greater. In loudness, however, assimilation commonly exceeds contrast (cf. Marks, 1993).

DeCarlo (1992) presented evidence suggesting that trial-to-trial assimilation in loudness may dissipate over a period of about 20 s. This time course is comparable to, or smaller than, the intervals commonly used in taste experiments, where expectoration and rinsing between trials typically lead to a relatively slow pace of stimulation, but longer than the intervals used in experiments showing assimilation in hearing and vision (e.g. Ward, 1979, 1982, 1985). Although it is difficult to increase the presentation rate of gustatory stimuli without risking substantial sensory interactions between successive stimuli, it is feasible to make the temporal conditions for loudness and taste comparable by reducing the rate of presenting the sounds. Consequently, Experiment 4 obtained judgments of loudness in the shifting-context paradigm when the tones were presented every 30 s, similar to the rate used with taste stimuli in Experiments 1–3.

Materials and method

Participants—Twelve participants (3 men and 9 women) between 20–35 years (mean = 25.2, sd = 3.7) took part, each serving in a single session.

Stimuli and design—In the single session, each participant received the same low and high sets of 500-Hz tones used in Experiments 2 and 3, presented under the same shifting-context conditions – but in the present experiment, the tones came at a rate of about 1 every 30 s, compared to about 1 every 6 s in the earlier experiments. And because of the longer ISIs, each session in Experiment 4 presented 8 blocks of trials (4 with each contextual set) instead of 16.

Results and discussion

The average normalized judgments of loudness, plotted in Figure 4, now give no evidence at all of assimilation, consistent with the results of DeCarlo (1992). Instead, the loudness judgments were slightly greater (9.3%, on average) when SPLs were low rather than high, a small albeit not significant amount of contrast, $F(1,11) = 1.383$, $p = .26$. Most importantly, the results show not a whiff of the substantial loudness assimilation typically observed with more rapid rates of auditory stimulus presentation, most notably, the results of Experiment 3, which tested loudness under similar conditions except for its shorter ISIs. Direct statistical comparison of Experiment 3 versus Experiment 4 (using a mixed ANOVA model with experiment a between subjects variable and context a within subjects variable) showed a significant interaction between experiment and context, $F(1,11) = 12.22$, $p = .002$. Thus, statistical analysis supports the conclusion that contextual assimilation in loudness declined as ISI increased.

The results of Experiment 4 hint at a small, albeit non-significant loudness contrast, although the present experimental paradigm typically produces assimilation with smaller intervals between successive stimuli. Loudness contrast can be revealed, however, through related, but more complex, experimental designs that neutralize assimilation by manipulating stimulus context in a complementary manner at 2 different sound frequencies (Marks, 1993, Experiments 10–13). Loudness contrast is specific to the sound frequency (Ward, 1990) and may largely reflect what has been called ‘induced loudness reduction’ – a decrease in loudness that occurs when a test tone is preceded by a more intense conditioning tone of the same or similar frequency (Nieder, Buus, Florentine, & Scharf, 2003). Further, induced loudness reduction itself declines relatively slowly, taking several minutes to disappear (Arieh, Kelly, & Marks, 2005), unlike loudness assimilation, which seems to largely disappear in about 20 s (DeCarlo, 1992). Thus, assimilation and contrast in loudness have different time courses. The small amount of loudness contrast and, notably, the absence of assimilation observed in Experiment 4 resemble the taste contrast and lack of assimilation observed in the previous experiments. Perhaps both assimilation and contrast also take place in taste perception but, as in hearing, also have different time courses.

General discussion

Contextual effects pervade judgments of perceptual intensity, as well, of course, as other realms of judgment. Although psychophysical research has focused on the ways that stimulus context affects the judgment of perceptual magnitudes, especially perceived intensity, contextual effects arise in many judgments, including, importantly, the identification of stimuli. When the stimuli being identified differ in their physical level, identification responses, like intensity judgments, often show sequential assimilation – that is, people tend to make the same response to the current stimulus as they made to the stimulus on the previous trial (see summary by Stewart et al., 2005). Because assimilation is so pervasive in judgments of perceived intensity and in identification, and because assimilation appears to be closely tied to processes of decision and response, transcending particular sensory modalities (Ward, 1982, 1985), it was surprising that the present experiments did not reveal any clear assimilation in judgments of taste intensity.

Nevertheless, the absence of contextual assimilation in the present judgments of taste intensity is consistent with earlier reports (Riskey et al., 1979; Riskey, 1982; Schifferstein and Frijters, 1992; Schifferstein & Oudejans, 1996; Marks et al., 2012; Hallowell et al., 2016), all of which found evidence of contrast but not assimilation in judgments of taste intensity. Like the present study, each of the just-mentioned studies presented the taste stimuli at relatively slow rates: Riskey et al. reported that most of the participants “finished the 52-beverage taste session within 40 to 50 min” (p. 172), implying that the taste stimuli were presented at a rate of about 1 every 46 to 58 s. Riskey (1982) tested three different procedures: In one procedure, there was no rinsing between trials, and the 55-stimulus session required about 40 minutes (implying that stimuli were presented about every 43 s); a second procedure was similar, but included rinsing, increasing the session’s duration to 45 min (stimuli presented about every 49 s); and a third procedure included a recovery period of 45 s plus two rinses, for a total duration of 75–90 minutes (stimuli presented about every 82–98 s).

Riskey (1982) found contrast with all three of his procedures, leading him to conclude that the contrast effects do not represent sensory adaptation. It is indeed plausible that these contextual effects do not arise from the same processes that lead to reductions in taste intensity with prolonged stimulation (Gent & McBurney, 1968); nevertheless, contrast produced by context-inducing stimuli does appear to be tied substantially to adaptation-like processes that are both modality-specific and stimulus-specific, both in taste (Rankin & Marks, 2000; see also Stevenson & Mahmut, 2010) and other modalities (Ward, 1979, 1985; Nieder et al., 2003; see Marks & Arieh, 2006). Indeed, in taste, hearing, and perhaps other modalities as well, contextual contrast seems to mainly represent reductions in perceived intensity in high contexts, without corresponding increases in perceived intensity in low contexts (Marks & Arieh, 2006). But it is likely that contrast can also reflect decisional processes. Although contrast is typically found in judgments given to test stimuli that follow context-inducing stimuli, a small amount of contrast may also arise in taste judgments when, for example, test stimuli precede context-inducing stimuli (Lawless et al., 2000).

To broadly summarize the present results, none of the findings on taste intensity (Experiments 1–3) showed clear evidence of contextual assimilation, with contextual contrast in taste appearing most clearly in Experiment 1 (with three different response scales). Judgments of loudness, however, showed assimilation in Experiments 2 and 3, where stimuli were presented at a relatively rapid rate, 1 about every 6 s, but not in Experiment 4, where the stimuli were presented at a slower rate, about 1 every 30 s, like the rate used in the experiments on taste. DeCarlo (1992) presented evidence suggesting that trial-to-trial assimilation in loudness may dissipate over a period of 20 s. Perhaps, in both taste and hearing, the decay of assimilation is more rapid than the decay of contrast – a potentially useful clue to clarifying the underlying mechanisms.

A definitive experiment in taste would use the shifting-context paradigm while presenting the taste stimuli at a sufficiently rapid enough rate, say, every 6 s, to reveal the anticipated assimilation – which we suspect is typically the net sum of a large assimilation effect, which declines quickly, and a smaller contrast effect, which declines more slowly. But developing and implementing such a paradigm are challenging, especially given the need to rinse sufficiently between trials in order to avoid the sensory adaptation that would reveal itself as contextual contrast, while also presenting a sufficiently large range of stimulus concentrations.

A final point: Contextual effects are widespread and pervasive. In taste perception, they involve not only the effects of earlier gustatory stimuli and their associated taste intensities, but also the simultaneous presence of associated non-gustatory flavorants – as, for example, when the judged sweetness of sucrose is increased by the simultaneous presence of an olfactory flavorant such as lemon or strawberry (e.g. Frank and Byram, 1988; Schifferstein & Verlegh, 1996). How people select and respond to the foods and beverages that they consume depends on the interplay of sensory and cognitive processes, including decisional processes and biases, that contribute to the contextuality of taste and flavor perception.

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Figure 1.

Average normalized ratings of taste intensity of sucrose obtained in Experiment 1 with 3 scales: magnitude estimation (MES), labeled magnitude (LMS), and visual analog (VAS). Within each session, contexts shifted repeatedly between low concentrations (open symbols) and high concentrations (filled symbols) of sucrose. All 24 participants rated taste intensity on all 3 scales, using each scale in a separate session.

Figure 2. Average normalized magnitude estimates of taste intensity of sucrose and loudness of 500-Hz tones from Experiment 2, measured in different sessions on the same 11 participants. Within each session, contexts shifted repeatedly between low concentrations of sucrose or low SPLs (open symbols) and high concentrations or SPLs (filled symbols). All sessions were run in a sound-shielded test chamber.

Figure 3.

Average normalized magnitude estimates of taste intensity of sucrose and loudness of 500-Hz tones from Experiment 3, measured in separate sessions on the same 12 participants. Within each session, contexts shifted repeatedly between low concentrations of sucrose or low SPLs (open symbols) and high concentrations or SPLs (filled symbols). All sessions were run in a sound-shielded test chamber.

Figure 4.

Average normalized judgments of loudness of 500-Hz tones in Experiment 4 measured in 12 participants. Within the sessions, contexts shifted repeatedly between low SPLs (open symbols) and high SPLs (filled symbols), with tones presented at a rate of approximately 1 every 30 s, compared to approximately 1 every 6 s in Experiments 2 and 3.