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Primacy and Recency Effects for Taste

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Historically, much of what we know about human memory has been discovered in experiments using visual and verbal stimuli. In two experiments, participants demonstrated reliably high recognition for nonverbal liquids. In Experiment 1, participants showed high accuracy for recognizing tastes (bitter, salty, sour, sweet) over a 30-s delay in a recognition task, even when the probe stimulus was only a different concentration within the same taste. In Experiment 2, participants tasted three liquids and showed both primacy and recency effects in a serial-position recognition task with varying delay lengths (15, 30, 45, 60 s). Recognition for liquids at the end of a list was most evident with shorter delay lengths (i.e., recency). Recognition for liquids at the start of the list was most evident with longer delay lengths (i.e., primacy). These data show that not only is gustatory information stored and maintained in working memory, but that memory for these liquids follow a recency-to-primacy shift in recognition memory.

Keywords: recognition, delayed match-to-sample, chemoreception, serial probe, working memory

Of the five basic senses, taste is perhaps the least studied and the least understood (Veldhuizen et al., 2011). Even if taste has not received the same attention as the other senses, its function is crucial: Taste portrays information about the qualities and properties of food. Taste can be used to determine what foods are nutritious and what foods are poisonous (Drewnowski, 1997), and a great deal of research has been dedicated to taste aversion (Gaston, 1978; Verendeev & Riley, 2012). Accordingly, memory research for taste has traditionally focused on long-term implications and conditioning. To date, there has been very little research dedicated toward how other forms of memory, such as working memory (WM), interact with taste. The present experiments aim to systematically study tastes using procedures commonly used to study WM.

Early research in the field of WM and taste suggests that humans may be unable to temporarily store accurate representations of tastes over a delay. Barker and Weaver (1983) argued that memories for sucrose solutions were inaccurate and prone to memory interference. Participants tasted a dilution of sucrose solution, after which one of four varying delays (1-min, 5-min, 15-min, or 72-hr) was presented. Participants were then asked if a second solution, identical to the first, was less sweet, sweeter, or equally sweet in comparison to the first solution. At the shortest delay, participants were unable to recognize the second solution as equally sweet as the first, and most often, they reported the solution as sweeter than the first. This trend remained across all delay lengths, and Barker and Weaver (1983) concluded this was because human memory is unable to accurately store representations of taste in a short-term store like WM.

Vanne, Tuorila, and Laurinen (1998) replicated Barker and Weaver's (1983) finding using a similar task. Dilutions of sucrose were mixed with either water (as a control) or a dilution of sodium chloride (salty), citric acid (sour), or caffeine (bitter). After varying delays, participants were asked to recreate the sweetness intensity of the sample liquid. Participants reliably miscalculated the absolute intensity of sweetness. Furthermore, the researchers found that additional, irrelevant tastes (i.e., sodium chloride, citric acid, or caffeine) had no effect on how participants remembered the sweetness intensity. This finding runs contrary to Stevenson and Prescott's (1997) finding that combining tastes reduces the remembered intensity of both tastants. The differences between Vanne et al.'s data and those of Stevenson and Prescott's and of Barker and Weaver's are likely due to task-specific details, such as having participants mix their own solutions ad libitum (Köster, Prescott, & Köster, 2004). Further commentary by Morin-Audebrand et al. (2012) posits that taste memory's function is to detect changes in tastes rather than storing previously encountered tastes.

Recent work by A. J. Johnson, Volp, and Miles (2014) tested WM for tastes using lists of three liquids. Participants were presented with a list of three wines and asked after a 5-s delay if a fourth wine was presented in the previous list. Participants showed highest recognition for wines presented in the first and last positions of the list, creating a U-shaped function for primacy and recency effects. These results show that participants were able to reliably recognize wines over a delay, but they do not confirm that tastes were stored in WM. Because olfaction, and therefore flavor, was not controlled, participants may be responding to olfactory cues rather than taste. Hence, an improved procedure is needed to test list memory for tastes. Specifically, a procedure is needed that would demonstrate recognition for tastes over a delay without additional visual or olfactory cues. Additionally, delay lengths should be systematically manipulated to explore the serial-position function which allows for a better understanding of the processes that produce the form of the function (cf. Wright, 1998).

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Experiment 1

The goal of Experiment 1 was to test whether liquids could be temporarily stored over a delay. By having a single-item recognition task examine one liquid at a time, we examined the effects of hedonic value, intensity, and verbalizability on memory. The hedonic value, or how pleasurable the liquid is, can be a predictor of memory strength in odors and tastes, particularly if the liquid is aversive. The reported intensity of the liquid will record the saliency of the taste, and it will ensure that, within this study, no single stimulus is disproportionately stronger or weaker than others. The verbalizability of the stimulus could be informative when compared to accuracy in the recognition task. Previous research suggests that the verbalizability of a stimulus may result in different levels of recognition accuracy based on delay length, with nonverbal stimuli resulting in poorer accuracy at longer delays (Engen & Ross, 1973; Zelano et al., 2009).

One of the goals of the current study was to create a liquid stimulus set. If one or more stimuli in the experiment created disproportionately higher, or poorer, accuracy, those liquid solutions would be altered until all stimuli were sufficiently different. This stimulus set would later be used in Experiment 2. An ideal stimulus set would result in recognition that is reliably above chance (50%), with accuracy being highest for liquids that are perceptually distinct (e.g., bitter and sweet), and accuracy lowest for liquids that are perceptually similar (e.g., varying degrees of sweetness). Participants performed a recognition task, where they were required to remember one liquid at a time over a delay. Afterward, they rated the specific qualities of every individual liquid involved in the experiment to measure and control for intensity, verbalizability, and hedonic value (cf. Zelano et al., 2009, Experiment 1).

Method

Participants. Participants were Auburn University undergraduate students enrolled in psychology classes participating for extra credit ($N = 34$). Participants were recruited for times between 9:00 a.m. and 5:00 p.m. with an hour taken off at noon to avoid possible contributing effects of lunch. During recruitment, participants were asked to not have eaten within the past 2 hr and to be nonsmokers. Ages ranged from 18 to 23 years ($M = 18.4$ years), with 23 of participants identifying as female, and 4 reporting that their left hand was their dominant hand. Four participants withdrew midstudy, and their data are not included in the subsequent results. Total participation in this study lasted no longer than 1 hr, and all participants agreed to an informed consent approved by the university's institutional review board.

Apparatus. Timing and data logging were handled by E-Prime 2.0 Professional running on Windows XP. All programs were custom written. Participants read all instructions and trial events while seated 30-cm away from a 17-inch LCD monitor (1280 × 1024, 60 Hz). Responses were recorded with a keyboard and mouse.

All liquids were stored in small 5-mL semiopaque plastic canisters with lids. Twenty-ounce cups were provided for liquid waste disposal when participants were done with their liquids. Throughout the experiment, distilled water was provided in 20-oz bottles along with nonbendable straws.

Stimuli. All liquids were created by mixing distilled water with one of four ingredients to emulate the basic tastes of salty, sour, sweet, and bitter (Chandrashekar, Hoon, Ryba, & Zuker, 2006). Mixing distilled water with these four basic tastes allowed all liquids to be equally clear and without any flavor, so participants were not given additional nontaste cues to solve the task. Each basic taste was varied along concentration to create eight total liquid stimuli. Table 1 presents the list of the eight liquids used in the current study along with their ingredients and concentrations, as determined by a pilot study. In this pilot study, different concentrations of tastes were tested to ensure that participants were able to reliably discriminate between two varying concentrations.

All stimuli were stored at room temperature, and all ingredients were mixed in advance to ensure solutions were well mixed or no longer carbonated. None of these stimuli included ingredients that are common in food allergies, such as lactose, peanuts, or Red Food Dye No. 4. All liquids were created on the day of data collection.

Procedure.

Recognition task. The researcher verbally described the experiment, pointing out the location of relevant procedural items and demonstrated appropriate gestures. Participants were given the following instructions: "After a short 30-second delay, you will be given a second liquid. If this liquid was identical to the first liquid, press 'F.' If this liquid was NOT identical (in taste, intensity, or both) to the first liquid, press 'D.' If the two liquids are different in any way, please press 'D.'" Once participants had no further questions and reported being comfortable with the task instructions, they were allowed to continue.

Before each trial began, the computer presented a dialog prompt asking participants if they were ready to begin the next trial. When participants acknowledged that they were ready to continue via pressing the spacebar, the computer displayed text prompting the participant to immediately taste the liquid from the cup in front of them. Cups were always placed in front and to the left of participants before the beginning of each trial. When participants were finished tasting the liquid, they discharge the contents of their mouths into a cup. Following the computer's visual instructions, participants tasted the sample stimulus for 4 s. Directly after the sample presentation was discharged into the cup, the computer prompted participants to take a sip of water in order to rinse their mouths, and they discharged this too into the waste cup. Participants were advised to rinse and discharge a sip of distilled water as a palette cleanser to eradicate any trace amounts of the sample liquid (E. A. Johnson & Vickers, 2004). This palette cleansing lasted 5 s, and a delay of 30 s directly followed. This delay length

Table 1
Description of Liquids Used in Experiment 1

Taste	Active ingredient	Weight/volume
Moderately sweet	Sucrose	4%
Highly sweet		8%
Moderately salty	Sodium chloride	2%
Highly salty		4%
Moderately sour	Citric acid	5%
Highly sour		10%
Moderately bitter	Quinine hydrochloride	2%
Highly bitter		8%

was chosen based on findings of Wright et al. (1985) that demonstrated primacy and recency effects with four-item lists for visual information. Additionally, this delay length produced the recency effect in a four-item list of auditory stimuli with monkeys, a good model for nonverbal memory (Wright & Roediger, 2003). During this delay, participants repeated the word *the* aloud at least once a second for the entirety of the delay. Repeating the word *the* aloud is a rehearsal suppression technique intended to disrupt verbal rehearsal so that information is not temporarily stored through linguistic codes (Baddeley, 2000; Saeki & Saito, 2004).

During the delay, the researcher placed the probe liquid in front of participants. With 2 s of the delay remaining, the computer prompted the participants to prepare to taste the probe liquid. After tasting the probe liquid, participants discharged the liquid into a cup and then responded via keyboard whether the two liquids were the "same" or "different." Feedback was provided after each response in order to avoid uneven response biases (Kantner & Lindsay, 2010). In the event of a correct trial, the word *CORRECT* in blue font appeared, and in the event of an incorrect trial, the word *INCORRECT* appeared in red font. Response time and cumulative accuracy was also presented below their feedback. Each trial was followed by a 30-s intertrial interval before the next trial began, and during this time, participants rinsed and spat to clear any residual taste from the probe liquid. A visual illustration of this trial progression is shown in Figure 1.

Each session contained 16 trials, where 8 trials were "same" discriminations and 8 trials were "different" discriminations. Liquids were pseudorandomly assigned before each session. The balance of "same" and "different" trials allowed each liquid to serve twice as the sample liquid, and once as the same comparison (i.e., a "same" trial). Each liquid also served once as the nonmatching comparison (i.e., a "different" trial). Of the "different" trials, half of these trials were between-tastes comparisons (e.g., moderately sour and highly salty) and the remaining four are within-taste comparisons (e.g., moderately sour and highly sour). The liquids making up these between-tastes and within-taste trials were pseudorandomly assigned so that no two trials had the same within-taste discrimination. In other words, if one trial compared moderately bitter to highly bitter, no subsequent trial would compare highly bitter to moderately bitter. All trial ordering was randomized across participants.

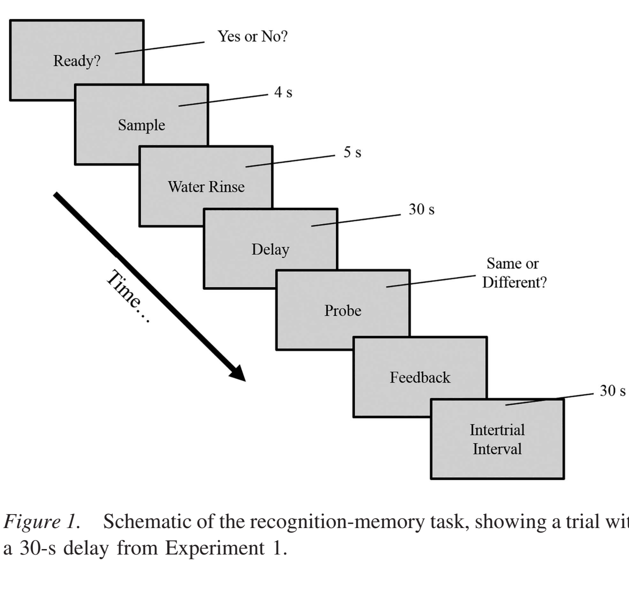

Figure 1. Schematic of the recognition-memory task, showing a trial with a 30-s delay from Experiment 1.

When participants completed all trials in the recognition task, they were asked if they had any questions regarding the task they just completed and if they needed a short break before continuing. When participants acknowledged that they were ready to continue, a short questionnaire was presented. The items on the questionnaire asked participants what strategies they used to solve the task, whether they altered their strategy across the session, if they believed the task to be too difficult, and if they ever found themselves bored or distracted during the task. If participants used visual, tactile, or verbal cues, or any other strategy to successfully memorize a liquid, this questionnaire may show a systematic trend among participants. After participants completed writing for each question, the researcher asked them to sit in front of the computer once more to complete a series of self-report measures regarding the current stimulus set.

Ratings task. Once ready, participants used the computer's mouse to respond along a visual analog scale with ratings of 0 to 100 and no anchors (Zelano et al., 2009). For each trial, participants tasted a liquid used in the previous recognition task and then responded to how pleasant, how intense, and how easily verbalizable was that liquid. Regarding pleasantness, participants were instructed, "Using the scale below, please indicate how much you enjoyed the current taste," with 0 being *I hated this taste* and 100 being *I loved this taste*. Regarding intensity, participants were instructed, "Using the scale below, please indicate how intense the current taste was," with 0 being *I could barely taste it* and 100 being *It was overwhelming*. Regarding verbalizability, participants were instructed, "Using the scale below, please indicate how easily verbalizable the current taste is," with 0 being *I can think of no words to describe this taste* and 100 being *I can easily think of a word to describe this taste*. Participants were presented with nine total liquids in this task—eight liquids were used in the current stimulus set, and one liquid was normal distilled water used as a control condition. Liquids were presented in a pseudorandomized order so that no basic taste was presented directly after itself; for example, "moderately bitter" and "highly bitter" could not occur consecutively.

After completing the final trial of the taste ratings task, participants were debriefed and allowed to ask any questions they may have had regarding the study. Bottled water was available for all participants upon their exit.

Results

Recognition task. Because proportions, such as accuracy, are not normally distributed variables, results were transformed using the arcsine square root transformation. Participants were able to successfully memorize liquids over a delay, as confirmed by comparing overall mean performance of each participant against chance (50%), one-sample t test: $t(29) = 9.62$, $p < .01$. Mean accuracy for the three trial types (Same, Between-Taste, and Within Taste) of Experiment 1 are shown in Figure 2. One-sample t tests found that accuracy for Same ($M = 74.17$, $SEM = 2.39$), Between-Tastes ($M = 76.67$, $SEM = 3.16$), and Within-Taste ($M = 60.83$, $SEM = 4.29$) trials were significantly above chance, ts(29) > 5.42, ps $< .05$. Additionally, a one-way repeated-

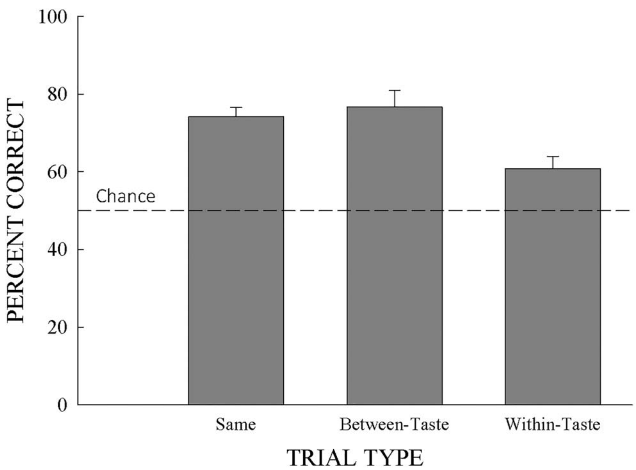

Figure 2. Mean accuracy across the trial types from Experiment 1. The dashed line represents chance accuracy (50%). Error bars represent the standard errors of the mean.

measures analysis of variance (ANOVA) on trial type (Same, Between-Taste Different, Within-Taste Different) found differences in accuracy across trial type, $F(2, 58) = 7.73$, $p < .01$, $\eta_p^2 = .201$. Post hoc pairwise comparisons tests showed that this difference is the result of poorer accuracy for Within-Taste discriminations compared to Between-Taste and Same discriminations ($ps < .01$).

Within-taste trials. Participants were better at discriminating some tastes than others, and this was confirmed by a one-way repeated-measures ANOVA of Taste (salty, sweet, sour, bitter), $F(3, 42) = 6.314$, $p < .01$, $\eta_p^2 = .179$. Post hoc pairwise comparisons showed that this difference was due to poorer accuracy for Within-Taste bitter discriminations, and accuracy for these bitter trials was significantly worse than any other Within-Taste discrimination ($ps < .05$). Poor accuracy on the Within-Taste bitter discriminations was due to a bias to respond "same"; 22 out of 30 participants responded "same" when presented with a moderately bitter and highly bitter liquid. An exact binomial sign test indicated that this ratio was significantly different from chance ($p < .05$).

Posttask questionnaire. One participant reported feeling bored during the task, but no one reported finding themselves unable to pay attention during the task. Three participants reported that they felt "full" at the end of the experiment. When asked if there was a particular strategy that they used to remember the liquids, 21 participants responded with specifically nonverbal accounts: "I remembered the tastes," or "Tried to remember the first taste of the trial," for example. Four participants responded with strategies that may have had verbal components, such as "I tried to remember if it was sweet, sour, or mediocre" or "I remembered if it was strong, or mild, or weak." The remaining participants declined to respond, stated that they had no strategy, or did not provide a relevant answer (e.g., "this stuff tastes terrible," or "the extra credit will be worth this"). Due to the subjective nature of these responses, it is difficult to draw conclusions about any systematic trends or strategies participants used in this task.

Ratings task. Liquids varied in intensity, as seen in Table 2. This result was confirmed with a two-way repeated-measures ANOVA of Taste (sweet, salty, bitter, sour) × Concentration (moderately, highly) that found a main effect of taste, $F(3, 87) = 55.85$, $p < .01$, $\eta_p^2 = .658$, and a main effect of concentration, $F(1, 29) = 58.73$, $p < .01$, $\eta_p^2 = .666$, but no interaction ($p = .06$). Participants rated high concentrations (e.g., highly bitter, highly salty) as more intense than moderate concentration liquids. Bonferroni-corrected post hoc tests showed that the main effect of taste was largely due to participants rating sweet liquids as less intense than all other liquids ($ps < .01$). Accuracy was not correlated with intensity ratings ($r = -.04$, $p = .44$).

Tastes varied in pleasure, as seen in Table 2. This result was confirmed with a two-way repeated-measures ANOVA of Taste × Concentration, finding a main effect of taste, $F(3, 87) = 15.54$, $p < .01$, $\eta_p^2 = .35$, no effect of concentration, and an interaction between the two factors, $F(3, 87) = 3.32$, $p < .05$, $\eta_p^2 = .1$. Bonferroni-corrected post hoc tests showed that the main effect of taste is largely due to participants rating sweet liquids higher than all others ($ps < .01$). Bonferroni-corrected post hoc paired-samples t tests showed that the interaction was due to participants rating Moderately Salty liquids as more pleasurable than Highly Salty liquids, $t(29) = 2.97$, $p < .01$, and no differences between concentration levels for each of the other liquids. Accuracy was not correlated with pleasure ratings ($r = .03$, $p = .45$).

Tastes varied in verbalizability, as seen in Table 2. This result was confirmed with a two-way repeated-measures ANOVA of Taste × Concentration, finding a main effect of taste, $F(3, 87) = 15.65$, $p < .01$, $\eta_p^2 = .351$, a main effect of concentration, $F(1, 29) = 28.72$, $p < .01$, $\eta_p^2 = .498$, and an interaction between the two factors, $F(3, 87) = 9.87$, $p < .01$, $\eta_p^2 = .254$. Bonferroni-corrected post hoc t tests showed that this interaction is due to participants rating sweet liquids as less verbalizable than sour and bitter liquids ($ps < .05$), and bitter liquids as more verbalizable that sweet or salty liquids ($ps < .05$). Additional Bonferroni-corrected post hoc t tests showed that the interaction was due to participants rating Highly Sweet and Highly Sour liquids as more verbalizable than Moderately Sweet and Moderately Sour liquids, respectively, $ts(29) > 3.71$, $ps < .01$, and no differences between concentration levels for each of the other liquids. Accuracy was not correlated with intensity ratings ($r = -.08$, $p = .10$).

Experiment 2

As a follow-up to Experiment 1, we developed a serial probe recognition test for testing list memory for tastes. By increasing the

Table 2
Means and Standard Deviations (in Parentheses) for Self-Report Values in Experiment 1

Taste	Intensity	Pleasure	Verbalizability
Moderately sweet	20.20 (17.82)	53.59 (18.38)	31.53 (25.23)
Highly sweet	50.12 (24.22)	51.46 (30.95)	56.06 (32.23)
Moderately salty	72.20 (15.46)	46.44 (31.24)	48.55 (31.04)
Highly salty	82.84 (16.15)	27.84 (24.00)	63.15 (25.17)
Moderately sour	53.89 (27.78)	29.20 (20.70)	44.03 (25.57)
Highly sour	76.12 (19.12)	26.46 (19.75)	86.38 (16.74)
Moderately bitter	68.55 (25.69)	18.24 (21.14)	82.66 (27.24)
Highly bitter	81.85 (15.66)	25.23 (24.17)	68.49 (30.05)
Distilled water	33.09 (17.44)	77.46 (17.18)	54.19 (36.79)

sample liquid in Experiment 1 to a sequence of three different liquids, this expanded the recognition memory task into a list memory recognition task. Participants tasted three sample liquids before a retention interval (delays of 15, 30, 45, or 60 s) and were asked if a separate probe liquid appeared in the previous list. Using a three-item list allowed us to test for serial position functions for tastes.

Method

Participants were undergraduate students recruited from Auburn University and the College of William and Mary ($N = 174$), and they were given the opportunity to participate in research in return for extra credit. Fourteen participants withdrew midstudy, and their data are not included in the subsequent results. Participants were randomly assigned to one of four groups ($N = 40$) for each tested retention interval. Ages ranged from 18 to 24 years ($M = 19.3$ years), with 102 of participants identifying as female, and 29 reporting that their left hand was their dominant hand. Total participation in this study lasted no longer than 1 hr.

Stimuli. The same stimuli used in Experiment 1 were used with the exception of the Moderately Bitter liquid which was diluted from 4% mg/L to 2% mg/L quinine hydrochloride. Pilot testing with 10 participants showed that participants were now able to sufficiently recognize the difference between Highly and Moderately Bitter.

Procedure. Participants went through the same briefing procedure as Experiment 1, and many of the experimental details were identical with two exceptions. First, there was a warm-up trial that allowed participants to become accustomed to the procedure. Second, was the expansion of the sample liquid into a list of three liquids (i.e., a three-item list). Participants tasted three liquids in each trial, with 4 s separating the onset of each stimulus. Within the 4 s, participants tasted and expectorated each liquid. Due to the nature of this stimulus administration, interstimulus intervals were impossible to precisely measure. During a delay of 15-s, 30-s, 45-s, or 60-s, participants were prompted to rinse, expectorate, and repeat the word *the* once a second until they were prompted to taste the probe stimulus. After tasting the probe, participants were asked if the probe stimulus was identical to one of the three tastes in the previous list.

Similar to Experiment 1, each session consisted of 16 trials, with 8 "same" trials and 8 "different" trials. Liquids were pseudorandomly assigned so that each taste appeared exactly eight times each session, four instances in "same" trials and four in "different" trials. A liquid was not repeated within the three-item list. There were no other restrictions on what liquids could appear in the list, so some lists could have varying concentrations of the same taste, or a "different" probe could be a different concentration of a taste that appeared in the trial's list. Each liquid served as a "different" and "same" probe once. Within the "same" trials, the probe stimulus may have been previously presented in List Position 1, 2, or 3, with each serial position tested at least twice each session.

Results and Discussion

Figure 3 shows mean recognition accuracy across list position and delay length. As can be seen in Figure 3, a recency-to-primacy shift occurs as the delay increases. At the shortest delay (15 s) a recency effect was found with accuracy highest at the end of the list compared to the beginning of the list. For the two middle delays (30 s, 45 s), a stronger U-shaped function appears across list position. For the longest delay (60 s) a primacy effect was found with accuracy highest at the start of the list than the end of the list. This recency-to-primacy shift was confirmed by a two-way mixed-model repeated-measures ANOVA of delay (15 s, 30 s, 45 s, 60 s) and list position (1, 2, 3). This ANOVA found a significant interaction between the two factors, $F(6, 312) = 2.96$, $p < .01$, with no main effect of delay ($p = .47$) or list position ($p = .06$). The interaction was due to accuracy on list position 1 increasing 15.9% over the increasing delays, $t(78) = 2.8$, $p < .01$, and accuracy on List Position 3 decreasing 22.6% over the increasing delays, $t(78) = 2.27$, $p < .01$. In addition, participants were able to perform the serial-position recognition task at all delays without any strong "same" or "different" bias, as confirmed by the following analyses. Recognition accuracy was significantly above chance (50%) for all delay lengths, one-sample *t* tests, $ts(39) > 8.62$, $ps < .01$, and accuracy was above chance for both "same" and "different" trials for all delay lengths, $ts(39) > 3.27$, $ps < .01$. At shorter delay lengths (15 s, 30 s), "same" trial accuracy was lower than "different" trial accuracy, as confirmed by paired-samples *t* tests, $ts(39) > 2.79$, $p < .01$. At longer delay lengths (45 s, 60 s), "same" trial accuracy was equivalent to "different" trial accuracy, $ts(39) < 1.42$, $ps > .16$.

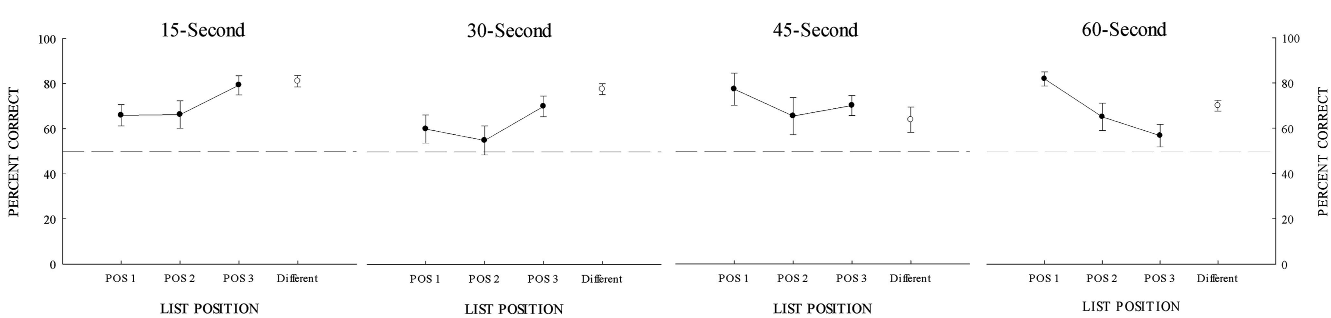

Figure 3. Mean accuracy for list positions across 15-s, 30-s, 45-s, and 60-s delay lengths in the list memory task. Solid circles show accuracy for "same" trials; open circles show accuracy for "different" trials. The dashed line represents chance accuracy (50%). Error bars represent the standard errors of the mean. POS = position.

General Discussion

Across these two experiments, participants demonstrated the ability to remember tastes across delays. The results suggest a sensory-specific short-term store for tastes, similar to those found in vision and hearing. Short-term memory (STM) for vision and hearing is characterized by a sensory-specific, brief, high-resolution representation that is sensitive to within-modality interference. The findings of Experiments 1 and 2 show a similar brief, high-resolution representation for tastes. These findings are at odds with the popular multicomponent model of WM which offers no such store for taste (Baddeley, 2012). However, Baddeley speculates the existence of a separate subsystem for taste, similar to those of vision and hearing, and the current results confirm this speculation. The existence of a taste store concurs with predictions of Postle (2006) and Jonides et al. (2008) and suggest that a further revision to Baddeley's model is warranted.

The results of Experiment 1 are also in direct contention with past research that memories of taste are unreliable (Barker & Weaver, 1983; Stevenson & Prescott, 1997; Vanne et al., 1998). The difference between the current study and these previous studies lies largely with what is being asked of the participant. Rather than asking participants if the probe liquid is less, more, or equivalently intense as the sample liquid, Experiment 1 had participants respond if the two stimuli were "same" or "different." Participants were specifically instructed that if the two liquids were identical in taste and intensity to respond "same." Experiment 1's stimuli varied along two distinct dimensions: taste and concentration, whereas prior research has often focused primarily on memory for differences in concentration.

The results of Experiment 2 demonstrate serial-position effects for tastes. Memory functions for list position were created by testing participants with three-item lists of liquids. At the short delay (15 s), participants show a recency effect, with the final liquid of the list being recognized most accurately. At the longest delay (60 s) this effect shifts so that the first liquid of the list is most accurately recognized, thus creating a primacy effect. The intermediate delays (30 s, 45 s) yield U-shaped functions which additionally capture the shift from primacy to recency over the delay intervals. These experiments not only show that participants can encode and store multiple liquids at once, but that this STM is susceptible to the same recency-to- primacy shift found in visual list memory (e.g., Wright, 1998). One explanation of the recency and primacy effect is the combination of within-list proactive and retroactive interference. At the short delays, the liquids at the end of the list interfere with the liquids at the start of the list (i.e., retroactive interference). As the delay increases and retroactive interference dissipates, the liquids at the start of the list interferes with the liquids at the end of the list (i.e., proactive interference). These typical recency-to-primacy shifts have been reported almost exclusively in visual and auditory domains, and there is a possibility that interference patterns are different for chemical senses like olfaction (Engen & Ross, 1973; Herz & Engen, 1996, for a review). In the future, parameters can be manipulated (e.g., list length, encoding time, interstimulus interval, delay, stimulus set, rehearsal) to further test the role of interference within and between lists on taste memory.

The recency-to-primacy shift reported in Experiment 2 may also be explained using the relative distinctiveness principle (Surprenant & Neath, 2009). In other words, primacy and recency effects are a result of how distinctive stimuli are in comparison with one another at the time of recognition. Based on this account, liquids presented second in the list are less distinct than their neighbors, which were presented at the beginning or end of the list, because the first and last liquids of the list only have one neighbor to compete with (i.e., List Position 2). With the shortest probe delay, the last liquid is the most distinct of the list, with very little time or neighboring stimuli interfering with its distinctiveness. As the probe delay increases, this last liquid becomes less distinct in comparison with the first and second liquids. The Scale Invariant Memory and Perceptual Learning model, which predicts changes in relative distinctiveness across stimuli (Gordon, Neath, & Chater, 2007), can be used in future studies to examine how similar memories for tastes compare to more commonly studied senses.

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