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Older US adults like sweetened colas, but not other chemesthetic beverages

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Abstract

Many older adults suffer from difficulty swallowing thin beverages like water or coffee. To improve swallowing safety, beverages are typically thickened. This creates a new problem: the thickened beverages can be disgusting. New research suggests chemesthesis, particularly spiciness, carbonation, or intense sourness, could improve swallowing without the need for thickeners. Yet, whether such beverages would be liked by older adults is unknown. We thus conducted this experiment to establish older adults' sensory perception and liking/disliking of commercially available chemesthetic beverages. We recruited participants to rate sweetness, sourness, fizziness, stinging, and liking/disliking of unsweetened carbonated waters (1 plain, 5 flavored), sour orange juice, spicy ginger beer, and colas (sugar or aspartame sweetened).

Initial tests (N=30 older adults) indicated sour orange juice, spicy ginger beer, and two of the flavored waters were not well-liked, so the other beverages were selected for a second test (N=94, 30 younger adults, 64 older adults). Sweetened, carbonated colas were the best liked of the beverages. The unsweetened, flavored carbonated waters were in general not liked. Regarding comparisons of sensory ratings between older and younger adults, only sweetness differed between age groups. In particular, intensity ratings for the chemesthetic aspects of the beverages (stinging/burning/spiciness, fizziness) and sour taste did not differ by age. As the chemesthetic properties are the most likely reason the beverages could aid in swallowing safety, observing no suppression of these sensations in older adults is encouraging for the potential of these products as a treatment option.

Keywords

dysphagia; beverages; palatability; carbonation; chemesthesis

Introduction:

Swallowing difficulty (dysphagia) affects a diverse population of patients with stroke, head and neck cancer, Parkinson's disease, or other neurodegenerative conditions. Yet, dysphagia

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Author Contributions

MRW executed the experiment, analyzed data, and drafted the manuscript. CRC assisted with data analysis and manuscript drafts. CAR designed and oversaw the study, analyzed data, and drafted the manuscript.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon request.

also affects many older adults who may be otherwise healthy. One in twenty-five adults are affected by swallowing problems annually (Bhattacharyya, 2014) and this number is only expected to rise as the population ages. For those who struggle to swallow thin liquids, the most common current treatment is to thicken the liquids. These thicker liquids are more likely to be swallowed safely, at least in acute trials, as the thickness slows down the movement of the beverage. This allows the airway additional time to close (Clavé et al., 2006; Logemann, 1993; Steele et al., 2015). However, the thickened beverages have their own problems compared to thin beverages. First, patients still aspirate thickened beverages, just less frequently than thin beverages (Logemann et al., 2008; Robbins et al., 2008). Further, when the thickened beverages are aspirated, the thick consistency makes it much harder to expel from the airway and thus can actually increase risk for aspiration pneumonia (Steele et al., 2015; Sue Eisenstadt, 2010). Additionally, patients often find the thickened beverages unpalatable, as the thickness is incongruent with the sensory expectations (i.e., water should not feel like slime). Consequently, patients prescribed thickened liquids may refuse to comply with the treatment or may drink inadequate quantities of fluid (Finestone et al., 2001). Drinking too little can result in dehydration, putting patients at additional risks for malnutrition and infections (Matta et al., 2006). Thus, alternate treatments to manage dysphagia of thin liquids are needed.

New work suggests chemesthesis, chemically induced temperature and irritation, could improve swallowing safety without thickeners (Krival, 2007; Logemann et al., 1995; Rofes et al., 2013; Running, 2016). Spiciness, stinging from carbonation, and intense sourness are chemesthetic sensations that have demonstrated potential for improving swallowing safety, usually by speeding up the swallow. Carbonation induces the physical texture of bubbles but also a chemical sensation of stinging or irritancy from carbon dioxide (Wise et al., 2013). Carbonated liquids have been shown to reduce occurrence of penetrations and aspirations, pharyngeal retention, and pharyngeal transit time (Bulow et al., 2003; Sdravou et al., 2012). Additionally, carbonation and spiciness may increase neuromotor activity compared to water during the oral stage of swallowing (Krival & Bates, 2012; Nakato et al., 2017). Similarly, sourness from relatively high concentrations of citric acid or lemon juice reduced aspiration and penetration occurrence (Logemann et al., 1995; Pelletier & Lawless, 2003).

However, these chemesthetic sensations may present a new version of an old problem—they are all potentially unpalatable, as they are chemical irritants. To be a viable option for treatment of dysphagia, these chemesthetic sensations must be palatable enough to consume. Before large, expensive swallowing safety trials for chemesthetic beverages proceed, we should consider what beverages will be most likely to address the problem of palatability, particularly among older adults. Diluted hot sauce, while very useful for fundamentally demonstrating the potential of spiciness to improve swallowing (Rofes et al., 2013), is unlikely to be consumed by older US adults. Yet, beverages such as spicy ginger beers, cinnamon drinks, and a vast array of carbonated drinks are already available at grocery stores. We hypothesized that some of these beverages might be palatable to the older population that commonly suffers from dysphagia.

Thus, we designed this study to assess whether a variety of commercially available beverages, particularly carbonated ones, might be liked by older adults. As these beverages

are easily obtained at regular grocery stores, they would be ideal for treatment—if their efficacy at inducing safer swallowing can be established in later trials. Here, we present our findings on how older adults, as well as a smaller group of younger adults for comparison, rated the sourness, fizziness, stinging/burning/spiciness, sweetness, and liking/disliking for a variety of commercially available chemesthetic beverages.

Methods:

The study was reviewed by the Purdue University Human Subjects Review Board, and determined to be exempt research under category 6, tasting of whole foods and food ingredients (Purdue IRB 1705019251). Participants were provided with a list of ingredients found in the beverages, and all participants verbally or digitally consented to participate in the test.

Samples

Beverages tested in these studies are described in Table 1. The ginger beer was donated by Q Drinks®, and all other beverages were purchased from local or online retailers.

Initial tests (“study 1”) indicated tart orange juice, spicy ginger beer, and two of the unsweetened, flavored carbonated waters (lemon, strawberry) were not well-liked by older adults, so the other beverages were selected for a second phase of the experiment (“study 2”). All tests included plain carbonated water. The pH of all beverages was measured in triplicate using a calibrated Mettler Toledo FiveEasy Plus pH meter and pH electrode LE 438. Cans/bottles of the beverages were opened and all replicate measurements completed within 15 minutes, so that loss of carbonation did not inflate the recorded pH values. The primary reason to record the pH of the beverages is in case these data are useful for future studies on swallowing safety.

Participants

A total of 124 participants (30 for study 1; 94 for study 2) volunteered for this study (87 female, 36 male, 1 no answer, 0 other). A summary of how many participants elected to taste each beverage in each study is shown in Table 2. The participant age distributions are shown in Table 3. While the main goal of this work was to establish how older adults perceived the beverages, some of the data collection occurred in public venues with wide varieties of ages present. Thus, we have data from 30 younger adults (under 55 years of age) as well. These data are included for preliminary comparisons only.

Tests

Sensory tests were conducted at a local farmers market, retirement community, and a local senior center in Lafayette and West Lafayette, Indiana, USA. Samples were aliquoted (kept for a maximum of 1 week at 4°C) into 59 mL (2 fl oz) amber bottles sealed with polyethylene cone lined caps, which we verified in preliminary tests could maintain carbonation of the beverages.

Plain carbonated water was included in the sample set, but we did not expect this unflavored sample to fare well in the hedonic ratings. This sample was always served first, which achieved two goals: 1) providing a target for first sample bias, as the first sample is often rated as more intense than subsequent samples, and 2) mitigating the influence of desensitization to chemesthesis on the other samples (Running, 2018), which were of greater interest from a translational science perspective. The ginger beer sample was always served last in order to avoid carryover effects from spiciness. Other samples were served in counterbalanced order (using a Williams' design) after the plain carbonated water (all subjects) but before spicy ginger beer (study 1 only). The Williams' design was maintained by printing and stapling the paper ballots together in the assigned orders for each subject (i.e., within each row of the Williams' design), and then stacking the ballots together in the assigned between subject order (i.e., row 1, row 2, row 3, etc. of the Williams' design) for distribution to participants as they volunteered for the study.

Paper ballots were used in order to avoid any issues with technology and to allow the use of large font. Each sample had its own rating page, an example of which is included in the supplemental files. The top of the page indicated what sample was to be tasted. In more typical sensory experiments, we would blind subjects to the identity of beverages in order to avoid bias for or against certain flavors. However, as the long-term goal of this research is to use these beverages in a free-living environment, it was more appropriate to inform subjects of the samples' identities. This also allowed participants to skip a beverage if they desired. Thus, the description of each sample was given at the top of each sheet, as listed in Table 1. Participants were instructed to rinse their mouths with water (spring water, provided in bottles), before tasting each sample. All participants were required to taste the plain carbonated water (served first). For all other beverages, participants were informed of the sample's identity, then asked if they were willing and able to drink that beverages. If a participant indicated they were unwilling or unable to drink the beverage, they proceeded immediately to the next sample. If the participant indicated they were willing to drink the beverage, they were instructed to take one drink from the bottle and swallow it. Then they were instructed to take a second drink and answer the sensory questions. The sensory questions included intensity ratings for: "sweet," "sour," "fizzy or bubbly," and "stinging, burning, or spicy." Ratings for these questions were collected on a numbered category scale of 0 to 6, with descriptors of:

0	Not at all
1	Barely detectable
2	Weakly
3	Moderately
4	Strongly
5	Very Strongly
6	Extremely

These descriptors were adapted from commonly used generalized labeled magnitude scales (Bartoshuk et al., 2003; Green et al., 1993; Kershaw & Running, 2019). We elected to use

these descriptors instead of a generalized line scale because we were concerned that differences in hand dexterity, due to age or age-associated conditions, could cause a loss of precision on a line scale. The intensity questions were followed by a hedonic question asking how much the participant liked or disliked the beverage. This was a 5 pt hedonic scale, using the following terms:

1. Dislike extremely
2. Dislike
3. Neutral
4. Like
5. Like extremely

Only the text for the hedonic scale was shown to participants (i.e., responses were coded as 1 – 5 after data collection). Last, participants were asked if they would be willing to drink this beverage daily. Answer options were “No” or “Yes.” Participants were not required to drink the entire vial of beverage.

Analysis

The data was analyzed using linear mixed models (the mixed procedure) in SAS 9.4, run in Jupyter Lab (annotated python code with embedded SAS code is available in the supplemental files). Linear mixed models are similar to analysis of variance (ANOVA) but allow for better incorporation of random/fixed factors, multiple levels of repeated measures, and a variety of covariance structures to fit those repeats. Linear mixed models also allow missing data, which is critical considering we allowed participants to skip beverages they were unwilling or unable to consume. Bar-histogram plots were created using OriginPro 2020. Although we collected our data on category scales, analysis of similar Likert scales shows these types of data can meet parametric model assumptions (namely that residuals are independent and identically distributed) and provide more robust analysis than non-parametric approaches (Norman, 2010). Additionally, even assumed “ratio” level line scales such as the labeled magnitude scale (Green et al., 1993), whose tick labels we adapted for our intensity categories, show “lumping” behavior around the tick marks (Hayes et al., 2013; Kershaw & Running, 2019). This clustering of ratings indicates a categorical type behavior in respondents on labeled magnitude scales, indicating these scales also do not truly provide “ratio” level data. While we would encourage readers to not assign ratio level judgements on any outcomes (i.e., a mean/median near “strongly” should not be considered “double” the intensity of a mean/median near “weakly”), the more general interpretation of one group of ratings being larger than another is acceptable (i.e., ratings centering near “strongly” are more intense than ratings centering near “weakly”).

The model (run independently for ratings of sweet, sour, fizzy or bubbly, and stinging/burning/spicy) we used for study 1 was:

$$\text{Rating} = \text{Beverage}$$

Where Beverage was the sample type.

The model for study 2 was:

$$\text{Rating} = \text{Beverage Gender AgeGroup Beverage*AgeGroup}$$

Where Beverage was again the sample type and AgeGroup was classification as “older” or “younger” adult. Other interactions (Gender*AgeGroup, Beverage*Gender) were not significant and so were removed from the model.

In all models, the Kenward Roger approximation was used to calculate degrees of freedom (Kenward & Roger, 1997; *SAS Help Center: Kenward-Roger Degrees of Freedom Approximation*, n.d.; *SAS Help Center: MODEL Statement*, n.d.). Subject was set as a repeated factor, and the covariance structure was set to compound symmetry. Least squared means were generated and compared for each effect (Tukey-Kramer adjustments for multiple comparison, with the adjust degrees of freedom by row option). Residual distributions for each model were checked to verify model assumptions were not violated. For study 2, least squared means estimates were calculated using contrast statements for: sweetened, flavored compared to unsweetened, flavored beverages (in other words, sweetened to unsweetened but excluding plain carbonated water); sugar sweetened to aspartame sweetened cola; unsweetened flavored carbonated waters to plain, unsweetened carbonated water. Residuals for study 2 ratings of sourness and stinging/burning/spiciness showed some positive skew, so any noted significant outcomes were also verified using Wilcoxon Sign Rank tests comparing the average within-subject ratings for the contrast groups (i.e., average all sweetened cola ratings compared to average all unsweetened, flavored carbonated water ratings within a subject). Notably, all noted significant differences for both sourness and stinging/burning/spiciness were also significant using the non-parametric alternative. Thus, we present here the findings from the original model, which can better handle missing data as well as adjust for covariance compared to the non-parametric alternative. The code and output tables for the non-parametric tests can be found in the supplemental files.

Notably, we expect the outcome of the last contrast (unsweetened, flavored carbonated water to plain carbonated water) to be biased against the plain carbonated water because that sample was served first in all studies. However, we thought the comparison of some ratings, such as sweetness or sourness, may be of interest for later research. In any case, results from that comparison should be interpreted cautiously. Additional contrast statements were also used to analyze the interaction of age group with these contrasts. The detailed SAS code can be found in the supplemental file.

Results:

As noted, the ratings for the beverages in study 1 were generally low. These ratings are included in the figures for the reader’s benefit, but we will focus on the outcomes from the larger sample size in study 2. All results tables from the SAS code (Type 3 Effects, Least Squared Means, Least Squared Means Differences, Least Squared Means Estimates [from contrast statements]) are available in the supplemental file.

Results are shown in Figures 1–5. The figures display the data as histograms of how many participants selected each number/category on the scale. There were no effects of gender.

Disliking/Liking

Patterns of liking/disliking are shown in Figure 1. The linear mixed model indicated that there were main effects on liking/disliking for type of beverage ($p=1.4\times 10^{-17}$) and an interaction of beverage with age group ($p=0.0041$). Contrast statements revealed the effects of beverage type are likely because participants liked sweetened (especially sugar-sweetened) colas more than unsweetened flavored carbonated waters ($p=7.4\times 10^{-16}$), and they liked the sugar sweetened cola more than aspartame sweetened cola ($p=4.6\times 10^{-5}$).

We also examined the contrast statements in order to evaluate the interaction of age group with beverage type. These contrast comparisons revealed that the interaction is most likely due to a larger magnitude of increased liking for sweetened beverages in the older adults compared to younger adults. From the least squared means estimates tables, the older adults rated sweetened colas a full category higher on the scale compared unsweetened, flavored carbonated waters, while for younger adults this difference was less than half a category (both differences were significant). Moreover, younger adults liked the sugar-sweetened cola more than most of the unsweetened carbonated waters (unadjusted all $p<0.032$, but adjusted p -values range from 0.009 to 0.66) but did not like the aspartame sweetened cola more than the unsweetened carbonated waters (all $p>0.05$). For older adults the greater liking of sweet colas compared to unsweetened carbonated waters are apparent for both sugar and aspartame sweetened colas (all adjusted $p<0.03$).

There may also have been trends for younger adults to like the peach carbonated water more than older adults (unadjusted $p=0.038$), and for older adults to like the aspartame sweetened cola more than younger adults (unadjusted $p=0.053$), but with the large number of comparisons of the interactions these do not survive the Tukey-Kramer adjustment.

Sweetness

Results for sweetness are shown in Figure 2. Main effects for age group and beverage type were apparent in the linear mixed model ($p=0.0073$ and 2.7×10^{-80} , respectively). Younger adults overall rated samples sweeter than the older adults. The effects of beverage type can be more clearly seen through the contrast statements. These reveal that regardless of age, the flavored carbonated waters were rated as sweeter than the plain carbonated water ($p=8.7\times 10^{-19}$). This is not particularly surprising, as the aromas would be expected to enhance perception of sweetness even when no sweetener is present. However, this effect should be interpreted carefully as the plain carbonated water was always tasted first. Both of the colas were rated as sweeter than any of the flavored waters ($p=4.7\times 10^{-65}$), which is also not surprising. The contrast statements also indicate that younger adults may have experienced aspartame sweetened cola as less sweet than sugar sweetened cola ($p=0.031$; older adults $p=0.73$). However, observing the ratings in figure 2 and consulting the least squared means table, the difference for younger adults between aspartame sweetened and sugar sweetened colas is still small (0.6 on an integer scale from 0 to 6), even if it was significant. This finding should be confirmed in a larger sample set of younger adults.

Sourness

Sourness had differences due to beverage type and possibly the interaction of beverage type and age group (Figure 3). Consulting the contrast statements, the differences among beverage types are primarily due to sweetened beverages being rated as less sour than unsweetened beverages ($p=1.6\times 10^{-17}$). Flavored, unsweetened carbonated waters were also rated as more sour than plain carbonated water ($p=0.050$), an effect that appears to be caused only by the older adults ($p=0.017$; younger adults $p=0.44$).

Fizziness and bubbliness

For fizziness/bubbliness (Figure 4), we saw main effects for beverage type ($p=0.022$) and a trend for age group ($p=0.067$). Beverage type effects were due to plain carbonated water being rated as fizzier than flavored carbonated waters ($p=0.00064$), which again should be interpreted cautiously as the plain carbonated water was always tasted first. While this effect is plausible, the higher rating for the plain water could have been amplified by desensitization effects on the later beverages (Running, 2018). Both this pattern of higher ratings for the plain carbonated water as well as the potential trend for a difference between age groups could be explained by looking at the contrast effects, which indicate that mainly the older adults were rating the plain carbonated water higher ($p=0.011$, vs. $p=0.17$ for younger adults).

Stinging, burning, spiciness

The model effects were not statistically significant for stinging, burning, and/or spicy sensations (Figure 5), but some contrast statements showed potential effects. Notably, older adults rated the sweetened colas as less stinging/burning/spicy than the unsweetened carbonated waters ($p=0.00034$).

Discussion

Sweetened carbonated beverages were rated highest for liking among several commercial (or easy to make from commercial ingredients) chemesthetic beverages. Thus, sweetened carbonated beverages may be the most promising option for future work on the effectiveness of commercially available chemesthetic beverages to manage dysphagia. However, this presents new challenges. Sugar contributes to poor oral health, which could aggravate any risk of pneumonia if the beverage is aspirated (Müller, 2015; Ortega Fernández & Clavé, 2013). If individuals are willing to use low-calorie sweeteners such as aspartame, the problem of worsening oral health might be avoided (Ortega et al., 2014). Yet, many individuals avoid low-calorie sweeteners due to negative side tastes (such as bitter or metallic sensations) as well as concerns about potentially harmful effects from these compounds. The actual veracity of safety concerns for low-calorie sweeteners is beyond the scope of this study, but for some perspectives see: Carrocho et al., 2017; Roberts, 2016; Shankar et al., 2013; Sylvetsky et al., 2017. Nevertheless, the beliefs of consumers regarding the safety of such sweeteners are absolutely relevant to our objectives. If consumers refuse to use low-calorie sweeteners, then such products are not useful alternatives to sugar.

Thus, palatable unsweetened chemesthetic beverages would be useful as practical alternatives for managing dysphagia. However, the unsweetened, flavored carbonated waters we tested were in general not well-liked. Yet, these unsweetened drinks were perceived as sweeter than plain carbonated water. This is not particularly surprising, as many aromas can enhance the perception of sweetness (Noble, 1996). Our data should be considered cautiously, as the plain carbonated water was always presented first. This was intentional, so that any first sample bias or desensitization effects (Running, 2018; Vickers, 1988) would influence this plain sample more than the flavored samples. However, while the order of tasting may have suppressed the sweetness and augmented the fizziness of the plain carbonated water, the prior literature on how aromas influence sensations leads us to suspect these effects would be maintained if the samples were randomized.

The generally low ratings for unsweetened carbonated waters are rather discouraging for future use of these products to manage dysphagia. The lack of sweetener in these products means that oral microbial loads could be better controlled. Moreover, not using a sugar alternative avoids any issues regarding low-calorie sweetener safety or flavor concerns. Additionally, we expect these unsweetened carbonated products will continue to be readily available for years to come. Sales of unsweetened, typically flavored carbonated waters have grown over 50% since 2015, and predictions indicate continued double-digit growth for the foreseeable future (Mintel, 2019). Despite poor performance in sensory ratings in our current study, the growth of this category in the US market gives many options to tailor the product to personal preferences. While our current study did not demonstrate good sensory ratings for these products, the market data certainly give some indications that this product segment is growing. Such growth may indicate that more people are learning to like these beverages. Thus, more work could be done on whether older adults could learn to like flavored, carbonated, but unsweetened waters.

Stinging/burning/spicy, fizzy, and sour sensations were not rated differently between our older and younger adult groups. However, this should be re-tested in future research, as the small sample size of our younger adult group reduces our power to find a difference. This leads to a greater chance of a false negative. The distributions of these ratings as observed in Figures 4 and 5 certainly hint that the distributions may not be the same across age groups. Nonetheless, differences due to age were observed for sweetness. Consequently, we at very least must conclude that any potential age differences for stinging/burning/spiciness, fizziness, or sourness would have a smaller effect size than sweetness. Notably, the lack of an age-based differences in sourness and stinging/burning/spicy perception are also encouraging for future research on using these sensations to improve swallowing safety.

These findings (an age-based difference for sweetness but no age-based differences for chemesthetic/textural sensations) are critical to understanding any potential roles for commercial chemesthetic beverages in managing swallowing disorders. The precise mechanisms for how chemesthesia may improve swallowing safety for individuals with oropharyngeal dysphagia is unknown. Current theories center around the fact that chemesthesia is mediated through the same nerves and pathways as texture and proprioception (Loret, 2015; Pelletier & Dhanaraj, 2006; Pelletier & Steele, 2014; Running, 2016). Consequently, the lack of a chemesthetic intensity difference between the age groups

is promising for the effectiveness of these beverages in treatment. The sensations of taste and smell tend to be suppressed with age, either through polypharmacy or general age-related loss of function (Deems et al., 1991; Doty, 2018; Murphy, 1993; Schiffman, 1997). Confirming this suppression of sweetness in our older adults, but not seeing the same suppression for chemesthesis, means that these sensations may be preserved well enough to meaningfully contribute to stimulating the trigeminal nerve. Notably, other research emphasizing chemesthetic sensations also indicate no suppression of chemesthesis in older compared to younger adults; indeed, the numbers reported seem to even indicate higher ratings of chemesthesis in older compared to younger adults, though direct comparative statistics are not given (Pelletier & Steele, 2014). Consequently, if activation of the trigeminal nerve or some other sensitization-type mechanism is the pathway through which chemesthetic beverages could improve dysphagia, this work gives preliminary evidence that the chemesthetic sensations are not suppressed by aging.

Limitations

Observing that most of our beverages were not well-liked by older adults does not mean they are completely impractical as substitutes for thickened beverages. Potentially, the carbonated beverages could be the lesser of two evils, as a carbonated beverage could potentially be a better option than a thickened beverage for some individuals. In any case, research is still needed to understand if these commercially available (or easy to prepare, as with the sour orange juice) would actually be effective in improving swallowing safety. As most prior research with carbonated beverages has used a mixture of baking soda with acid (Krival, 2007; Sdravou et al., 2012), the degree of chemesthesis experienced from that mixture compared to commercial carbonated beverages is unknown. Stoichiometric calculations indicate that prior research's mixtures would be similar in carbon dioxide content to 6g of CO₂ per liter of water. This is similar or perhaps even less carbonation than could be expected from commercial beverages [(Ashurst et al., 2017), and confirmed in our own lab measuring weight lost after opening a carbonated product when evaporation is minimized]. However, carbonation immediately escapes when mixing baking soda with acid or when opening carbonated products, so the amount of carbon dioxide actually delivered to a mouth will vary.

Our sample size for younger adults was rather small, as well as limited to a local farmer's market venue. Whether that population of individuals is different from our older adults (mostly from local retirement village and bingo hall, with some from the farmer's market) is unknown. Ideally a larger sample size should be tested to confirm the observed differences or lack of differences between age groups. Nevertheless, the patterns of potential differences, and their expected effect sizes, are encouraging in that chemesthesis intensity from the products we tested is not (or at least less) different in older compared to younger adults.

Conclusion:

Sweetened, carbonated cola beverages were the best liked option for a readily accessible, chemesthetic beverage that might be useful in future research on beverages to manage

dysphagia of thin liquids. However, sweetened options pose new potential problems related to oral health, pneumonia risks, as well as willingness of consumers to use the product. The unsweetened, flavored carbonated waters were in general not liked. More research would be needed to determine how to make an unsweetened option better liked by older adults. Regarding comparisons of sensory ratings between older and younger adults, only sweetness differed between age groups. In particular, ratings for the chemesthetic aspects of the beverages (stinging/burning/spiciness, fizziness) and sour taste did not differ between the age groups. As the chemesthetic properties are the most likely reason the beverages could aid in swallowing safety, observing no suppression of these sensations in older adults is encouraging. Further research is ongoing to determine if any of these chemesthetic beverages will improve swallowing safety, as well as to determine if these beverages, despite having relatively low liking ratings in isolation, would be preferable to thickened beverages.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Conflict of interest

The authors have no conflicts of interest to report. Author CAR has consulted for the food industry but has no funding from industry related to this project. Author CRC currently works for the food industry but was an employee at Purdue University when this research was conducted; her company had no influence or role in the project or drafting of the manuscript.

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Figure 1:

Liking/Disliking for beverages in both studies. Data are presented as histograms, with the box width reflecting the proportion of participants that selected that category from the scale. Significant differences are noted only for products in study 2 (beverages with both older and younger adult ratings). The last 4 beverages on the right were only tested in study 1 (the smaller group of older adults).

Figure 2: Sweetness intensity for beverages in both studies. Data are presented as histograms, with the box width reflecting the proportion of participants that selected that category from the scale. Significant differences are noted only for products in study 2 (beverages with both older and younger adult ratings). The last 4 beverages on the right were only tested in study 1 (the smaller group of older adults).

Figure 3: Sourness intensity for beverages in both studies. Data are presented as histograms, with the box width reflecting the proportion of participants that selected that category from the scale. Significant differences are noted only for products in study 2 (beverages with both older and younger adult ratings). The last 4 beverages on the right were only tested in study 1 (the smaller group of older adults).

Figure 4:

Fizziness intensity for beverages in both studies. Data are presented as histograms, with the box width reflecting the proportion of participants that selected that category from the scale. Significant differences are noted only for products in study 2 (beverages with both older and younger adult ratings). The last 4 beverages on the right were only tested in study 1 (the smaller group of older adults).

Figure 5: Stinging/Burning/Spiciness intensity for beverages in both studies. Data are presented as histograms, with the box width reflecting the proportion of participants that selected that category from the scale. Significant differences are noted only for products in study 2 (beverages with both older and younger adult ratings). The last 4 beverages on the right were only tested in study 1 (the smaller group of older adults).

TABLE 1:
CHARACTERISTICS AND BRANDS OF CHEMESTHETIC BEVERAGES USED

	Text displayed to participants	Brand	Sweetener	pH (Mean $\pm$ SD)	Ingredients	Study
<i>CARBONATED WATERS</i>						
<i>PLAIN</i>	Carbonated water (also called seltzer water)	Kroger® seltzer 12 oz can	None	4.00 $\pm$ 0.05	Carbonated water	Both
<i>VANILLA</i>	Vanilla sparkling water (unsweetened)	Polar Vanilla Seltzer 1 L bottle	None	4.00 $\pm$ 0.04	Carbonated water, natural flavor	1
<i>CHEERRY</i>	Cherry sparkling water (unsweetened)	Dasani® black cherry sparkling water 12 oz can	None	3.98 $\pm$ 0.04	Carbonated water, natural flavor	2
<i>STRAWBERRY</i>	Strawberry sparkling water (unsweetened)	Bubly™ strawberry sparkling water 12 oz can	None	3.88 $\pm$ 0.15	Carbonated water, natural flavor	1
<i>LEMON</i>	Lemon sparkling water (unsweetened)	Bubly™ lemon sparkling water 12 oz can	None	3.76 $\pm$ 0.01	Carbonated water, natural flavor	1
<i>PEACH</i>	Peach sparkling water (unsweetened)	Dasani® white peach sparkling water 12 oz can	None	3.71 $\pm$ 0.09	Carbonated water, natural flavor	2
<i>WATERMELON</i>	Watermelon lemonade (unsweetened)	Polar Watermelon Seltzerade 12 oz can	None	3.54 $\pm$ 0.12	Carbonated water, natural flavor, essence of fresh lemon	2
<i>OTHER BEVERAGES</i>						
<i>TART ORANGE JUICE</i>	Tart orange juice	75% v/v Simply Orange® pulp free orange juice with 25% v/v ReaLemon lemon juice	Orange juice	3.26 $\pm$ 0.09	Orange juice, lemon juice	1
<i>GINGER BEER</i>	Ginger beer (may be spicy)	Q drinks Ginger Beer 12 oz can	Agave	2.95 $\pm$ 0.01	Carbonated water, organic agave, ginger extract, citric acid, extract lime, coriander, cardamom, oranges, and chili pepper	1
<i>DIET COLA</i>	Diet cola beverage	Big K® diet cola 12 oz can	Aspartame	2.88 $\pm$ 0.05	Aspartame, caffeine, natural flavor, caramel color	2
<i>COLA</i>	Cola beverage	Big K® Cola 12 oz can	High fructose corn syrup	2.57 $\pm$ 0.06	Caramel color, high fructose corn syrup, caffeine, natural flavor	2

TABLE 2:
NUMBER OF SUBJECTS WHO DRANK EACH BEVERAGE

		Drank	Older	Younger
STUDY 1	<i>Plain carbonated water</i>	<i>Required</i>	30	--
	<i>Ginger Beer</i>	No	5	--
		Yes	25	--
	<i>Lemon carbonated water</i>	No	1	--
		Yes	29	--
	<i>Strawberry carbonated water</i>	No	0	--
		Yes	30	--
	<i>Tart orange juice</i>	No	1	--
		Yes	29	--
STUDY 2	<i>Plain carbonated water</i>	<i>Required</i>	64	30
	<i>Cherry carbonated water</i>	No	3	0
		Yes	61	30
	<i>Cola Beverage</i>	No	3	1
		Yes	61	29
	<i>Diet Cola</i>	No	6	2
		Yes	58	28
	<i>Peach carbonated water</i>	No	2	1
		Yes	62	29
	<i>Vanilla carbonated water</i>	No	3	0
		Yes	61	30
	<i>Watermelon carbonated water</i>	No	5	0
		Yes	59	30

TABLE 3:**PARTICIPANT AGES IN EACH STUDY**

	Average Age $\pm$ SD	Range
STUDY 1: OLDER ADULTS	74 $\pm$ 9 years	58 – 94 years
STUDY 2: OLDER ADULTS	74 $\pm$ 12 years	55 – 94 years
STUDY 2: YOUNGER ADULTS *	37 $\pm$ 10 years	24 – 54 years

* One participant in the younger adults group did not provide an exact age