A Multisensory Approach: The Effect of Deceptive Visual and Odor Cues on Flavor Perception

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Abstract

Previous research has examined the multisensory theory of perception which is that flavor is influenced by the integration of cues from the five senses: vision, smell, touch, taste, and hearing (Spence, 2015). While much of the research has investigated the effect of individual or multiple sensory information on flavor perception, there is little research investigating which of these senses has a stronger influence on flavor. This research study investigated whether vision or olfaction had a greater impact on flavor perception. A total of 68 participants (M_{age} = 21.79) drank sweetened water dyed a certain color and with a certain odor. The colors and odors either matched (i.e. purple color, grape odor), did not match (i.e. purple color, orange odor), or had only one sensory cue (i.e. purple color, odorless). Participants had to determine what flavor they perceived the sweetened water to be and their confidence levels in their answer. Results revealed that for the nonmatch condition, participants identified flavor based on color more than odor. For the single sense condition, participants identified flavor based on odor more than color. When two senses were presented, flavor perception was matched to the color and odor significantly more than when one sense was presented. It appears that the influence of sight and odor on flavor perception may be dependent upon the condition in which they are presented.

Keywords: flavor perception, multisensory theory, visual cues, odor

A Multisensory Approach: The Effect of Deceptive Visual and Odor Cues on Flavor Perception

Humans must consume liquids and foods on a daily basis to ensure survival. Since these are more readily available than they were in the past, flavor is a salient factor that influences drink and food selection. Auvray and Spence (2008) defines flavor as a multisensory experience, one that is influenced by multiple sensations and is more than only the taste of the food or drink. It is critical to note that taste and flavor cannot be interchangeable terms. Taste is different from flavor, as it is defined as the stimulation of the taste buds, which provide tastes such as sweet, salty, sour, bitter, and umami (Spence, 2012). Taste is as it relates to activation of taste buds, while flavor perception includes taste and all other sensory cues (Spence, 2012). According to the multisensory theory of perception, flavor is influenced by the integration of these cues from the five senses: vision, smell, touch, taste, and hearing (Spence, 2015). Therefore, the flavor of a food or drink can vary based on its visual cues of color, its odor, the sound of the crunch it makes, how many taste buds an individual has, and its texture. There are other cues that influence flavor such as temperature (e.g., how hot or cold a substance is) and irritation (e.g., spiciness and citrus elements; Delwiche, 2004). All these cues together contribute to the perceptual experience of flavor. Information obtained from one sensory experience and system influences the other senses, their neural systems, and processes (Delwiche, 2004).

One possible explanation for why flavor is influenced by multiple senses is because food is necessary for survival (Spence, 2015). Since humans do not have only one specific strategy to identify foods that are incapable of being consumed, poisonous, or unhealthy, it could be that using information from multiple senses provides more information in order to avoid eating rotten, poisonous and/or unhealthy foods. For example, when people look at a food or a drink, there are certain appearance cues that provide information about whether to eat or stay away from that substance. If an individual ate something that had a blue/green mold on it and had an unpleasant flavor or made them sick, that signals that this particular color may be harmful, and to not approach foods of that kind. In addition to visual cues, there are odor cues that indicate whether a food or drink is a threat or not. If something has a rotten or unpleasant smell, a human or animal will typically not approach that item (Delwiche, 2012). Every day most humans come in contact with food and drinks. Therefore, understanding how the senses and environmental cues interact regarding what is consumed will not only enhance eating and drinking, but add to the knowledge of sensory neural integration.

The goal of this research was to examine how visual cues (color) and odor influence flavor perception, specifically, which sense had a stronger effect when perceiving the flavor of a drink. Color has a significant impact on the identification of the flavor of a food or a drink (Delwiche, 2004). When a drink is inappropriately colored, it is more difficult to accurately identify what the flavor is (Zampini et al. 2007). Furthermore, varying the amount of color in a beverage can influence the perceived intensity of the flavor (Johnson & Clydesdale, 1982). In addition, odor has a strong influence on flavor perception, with much of what contributes to flavor is due to its odor (Rozin, 1996). There is a multisensory integration between orthonasal cues (i.e. when an individual sniffs something) and gustatory cues (i.e cues concerned with the sense of taste) that shape what a person determines a flavor of a food or drink to be (Spence, 2015). However, I was unaware of previous research examining the strength of color compared to odor on flavor perception. This is critical information because the senses are what allow humans to perceive and, possibly, react to what is consumed. Knowing whether visual cues of color or odor were stronger can provide information about how the brain responds to sensory stimuli and influence the way a person participates in the actions of eating and drinking.

In the following sections, I will describe the existing research on the effect of color and odor regarding flavor perception.

Effect of Odor on Flavor Perception

There is a neural integration between the senses of taste and smell (Dalton et al., 2000). According to Rosenblum (2010) 80% of taste is due to the sense of smell and frequently, when taste is altered or declining, it is often the result of damage in the olfactory system (Rozin, 1996). There are two ways in which the olfactory system is stimulated by food and drinks: orthonasal and retronasal. Orthonasal is when an odor is sniffed, and retronasal is when as an individual swallows, air is pushed out from the back of the nose (Spence, 2015). Retronasal smell is a direct part of the flavor perception experience, and orthonasal smell is what sets an expectation of a flavor (Spence, 2016). Additionally, the stronger the odor of food, the stronger the perception of taste (Frank et al., 1993; Hornung & Enns, 1986). If an association between a certain odor and taste exists, an odor by itself can stimulate a flavor perception. For example, when a chocolate odor is released into the mouth while a person is chewing flavorless gum, the person identifies the flavor of the gum as chocolate (as reported in Stillman, 2002). The reason that odor has such a strong impact on flavor is that smell is neurologically tied to taste receptors. Taste buds are activated by tastants, which have specific sensory cells that when stimulated overlap with those areas of the brain that are activated by odor, which is in the insula and operculum (Small et al., 1999; Poellinger et al., 2001). The taste and smell messages unite to help provide the perception of flavor, and this integration starts earlier in the flavor perception process than visual and auditory cues do (Mesuam, 1998).

Djordjevic et al. (2004) examined the effect an imagined odor compared to a perceived odor had on the detection of sweetness in a solution. An imagined odor is one that is thought of, while a perceived odor is directly smelled in real life. In Experiment 1 for the perceived odor group, researchers presented participants with two solutions, one with sweetener and one without, and participants had to identify which was sweet after smelling a sweet odor (i.e., strawberry) versus a savory odor (i.e., ham). For the imagined odor group, researchers presented participants with the same two solutions, but participants imagined the same sweet odor (strawberry) and savory odor (ham) while drinking the solutions. Before the testing began, participants were given a taste detection threshold test to ensure they could accurately identify the sweet solution. In addition, participants in the perceived odor group were given the odors to smell for familiarization, and the imagined odor group took time to practice imagining the odors of strawberry and ham. The dependent variable was the accuracy of identifying which solution contained sucrose. Across 60 trials, for perceived odor, participants smelled the odors (30 times for strawberry, 30 times for ham), then as quickly as they could, sipped the solution and spit it out. For imagined odor, participants imagined the odors (30 times for strawberry, 30 times for ham) while simultaneously sipping the drink. The accuracy in determining which solution was the sucrose solution was significantly better with the strawberry odor as compared to the ham odor for both the perceived and imagined odor groups. Since strawberry is a sweeter odor compared to ham, odors that have similar characteristics to a taste and are presented together regularly can enhance that taste. This also explains why the ham odor reduced the taste perception of a sweet solution. Moreover, these results revealed that an imagined odor produced the same results as the perceived odor, signifying the importance of smell on flavor perception.

In recent years, artificial intelligence technology has been developed in order to influence flavor perception through different modalities. Ranasinghe et al. (2017) introduced the AI called Vocktail which is a drinking utensil that can stimulate flavor perception. The Vocktail cup has a color projection system that uses LED lights to make the water in the cup appear a different color, three micro air pumps that pump out an odor for the user to smell while drinking, and a mouthpiece on the rim of the cup with electrodes that stimulate taste buds at different magnitudes to stimulate a certain taste sensation. The researchers used the different functions of the Vocktail to simulate four different taste configurations. The electrodes activated a salty taste sensation with a matching smell (smell : squid ink) and a non-matching smell (smell : vanilla); and activated a sour taste sensation with a matching smell (smell : lime) and a non-matching smell (smell : chocolate). Every trial the participants had to drink the water that was in the cup. The dependent variable was how the participants rated the taste of the water using a rate-all-that-apply scale for the words salty, sour, sweet, bitter, and umami for each independent variable condition. The researchers expected that the participants would have an altered flavor perception due to cross modal effects because of the layering of technologies, such as the LED lights, micro air pumps, and electrodes being used at the same time. For the salty taste sensation with a matching smell condition (squid ink), participants rated the water as tasting umami significantly more than salty, sweet, bitter, or sour. However, for the salty with a non-matching smell condition (vanilla), participants rated the water as sweet significantly more than the other flavors. For the sour taste sensation with a matching smell condition (lime), participants rated the water as tasting sour significantly more than salty, sweet, bitter, or umami. However, for the sour with a non-matching smell condition (chocolate), participants rated the water as sweet significantly more than the others. The authors concluded that an odor alone can alter the way an individual tastes a drink, above and beyond taste.

This study supports that an odor by itself has the strength to change the way a person perceives what they are consuming. However, the results examined the effect on flavor perception regarding odor alone, and did not investigate the effect on flavor perception pitting color and odor against each other.

Effect of Color on Flavor Perception

Spence (2016) described that altering the color of a drink can change the perceived flavor and intensity of the drink. When the color red is added to certain flavored drinks to resemble cherry flavored drinks, there is an increased rating of sweetness and intensity of the flavor as the color is darkened even though the composition of the flavor itself has remained the same (Johnson & Clydesdale, 1982). This occurs even when participants are told that they may be tricked by the color of a liquid and that it may not match the flavor (Zampini et al., 2007).

Furthermore, when a liquid is colored inappropriately, it is more difficult for someone to correctly identify what flavor the liquid is (DuBose et al., 1980).

Zampini et al. (2007, Experiment 1), investigated color-flavor associations. Participants were asked to look at samples of colored liquid and determine the flavor based only on the color. Participants were provided a list of options for the flavor, or they could write their own flavor. The results revealed that green was associated significantly with lime, yellow with lemon, orange with orange, gray with blackcurrant, blue with spearmint, and colorless with flavorless. The one color that was not significantly associated with a specific flavor was red, as it was significantly associated with strawberry, cherry, and raspberry. Experiment 2 investigated if the visual cue of color would affect accurate flavor perception. Since certain colors had significant associations with specific flavors, in Experiment 2 the researchers examined if a mismatch of color and flavor changed the perceived flavor. For example, examining participants' flavor identification of an orange flavored drink with a green color. In addition, the intensity of the perceived flavor was examined by coloring some of the drinks with a normal concentration of dye, and other drinks with a double concentration of dye. Each participant was given a transparent cup with a transparent room-temperature liquid inside it. Each liquid had the flavor of lime, orange, flavorless, or strawberry and had the colors of green, orange, colorless, or red. Additionally, a palate cleanser of deionized water, potassium chloride, and sodium bicarbonate was given to the participants to use in between each trial. Participants were required to identify the flavor of the liquids, and its intensity. The same list of flavors in Experiment 1 was used in Experiment 2 for flavor identification, and the Labeled Magnitude Scale was used for the ratings of intensity. The orange flavored liquids were identified significantly more when they were colored standard orange, darker orange, or colorless as compared to being green or red. The lime flavored liquid was accurately identified significantly more when it was standard green, darker green or colorless as compared to orange or red. Regarding intensity ratings, the lime flavored liquid was rated less intense when it was colored darker orange as compared to standard orange or colorless. Experiment 2 showed that overall, there was less accurate flavor identification when the color and flavor of the liquid did not match. This provides insight into the extent flavor perception is influenced by visual cues.

This is vital to my research since it explains what specific associations exist between different colors and flavors. Experiment 2 of Zampini et al. (2007) demonstrates that colors with more significant flavor associations have more easily identifiable flavors when tasted. Plus, if there is an incorrectly colored liquid with regard to its flavor, it is more difficult to identify the flavor of the liquid.

Dubose et al. (1980, Experiment 2) also examined the effect of color on flavor perception. The beverages were flavored cherry, lime, orange, and flavorless. The associated colors were red, green, orange, and colorless. The dependent variable was the accuracy of flavor identification. Each liquid flavor was presented four times, with only one time having the appropriate color (e.g., for cherry: cherry flavor - red color, cherry flavor - orange color, cherry flavor - green color, cherry flavor - colorless). Participants had to sip the liquid, then from a checklist check off the flavor they perceived the drink to be. For the cherry and orange flavored liquids, identification of flavor was more accurate when colored appropriately. For the lime flavored liquid, identification of flavor was significantly more accurate when colored green or colorless. Lastly, the flavorless liquid was accurately identified as flavorless across all conditions. These results indicate that the visual cue of color has an effect on flavor perception, and when there is an incorrect color, an individual may be influenced to report an inaccurate flavor.

Current Research

The goal of this research is to examine whether color or odor had a stronger influence on flavor perception. Since each of these senses contribute to flavor perception, knowing which sense has a stronger effect can help with the recognition of how senses are linked together as it pertains to the multisensory theory. The inputs from one sensory system affect the others, all of which influences the ability to make predictions about the flavor and palatability of the food and drinks that we consume (Spence, 2016). Since this study investigated the effects of visual and olfactory cues, there is insight regarding how an individual would perceive a flavor based on visual and olfactory sensory inputs. If there are certain aspects of foods and drinks that a person does not enjoy, knowing how the senses interact can potentially help enhance the eating and drinking experiences, and fill a gap in the existing research.

This research study was a within subjects design, with color and odor as the independent variables. The colors were purple, orange and red, while the odors were grape, orange and berry. The three conditions in the study were a match (i.e. purple color with a grape odor), a single sense condition (i.e. purple color with no odor, and no color with grape odor), and a non-match (i.e. purple color with an orange odor). Filtered water sweetened with artificial sweetener was used as the drink to be dyed and scented. The dependent variables were the perceived flavor of the drink and how confident participants were of their responses. The responses determined which of these senses had a stronger effect on flavor. If a participant identified a purple colored liquid with an orange odor as orange flavored, this participants' sense of smell was more influential, and if the participant identified a purple colored liquid with an orange odor as grape flavored, the sense of vision was more influential. The confidence rating scale investigated which combinations of colors and odors possessed more of an automatic association with a specific flavor. Even though the drink had no flavor, the expectation is that participants will have greater confidence in their flavor responses for the match and single sense trials than the non-match trials. Levitan et al. (2008) used a Likert scale for confidence ratings to assess whether participants were more confident in identifying a potential difference in the taste of chocolate candies with different colors for when the participants were blindfolded as compared to not blindfolded. The results indicated that participants had significantly higher confidence when they were not blindfolded.

I hypothesized that the perceived flavor will be more likely to match the color and odor when they matched compared to when only color or odor was present (single sense condition). When the color of a liquid was appropriate to the flavor, there is more accuracy in identification (Zampini et al. 2007) and when the odor was paired with the participant having the sweetened water in their mouth, the flavor and odor would be intensified (Dalton et al. 2000). This research question had not been tested before, however based upon the neurological link between odor and taste, I hypothesized that flavor perception will match the odor more than color, for the non-matched and single sense trials. Rosenblum (2010) explained that 80% of what we taste is due to smell. Even though there was the visual cue of color that could set an expectation, much of what we perceive as a flavor comes from the sense of smell which has the potential to sway the participant in the direction of the odor. Additionally, with the existing knowledge of the neurological link between the olfactory and gustatory systems, an odor has the potential to overpower the sensory influence of a color.

Methods

Participants

The total number of participants was 68 (M_{age} = 21.79, SD = 5.07) and were recruited from Stockton University via SONA. The number of participants for this study was determined by previous research, and 20 people per condition, (with my study having three different conditions) was optimal. Participants were 84.4% female, 14.1% male, and 1.6% preferred not to answer. Eighty-two percent identified as White, 9.2% were Asian American or Asian, 3.1% were African American or Black, 3.1% were biracial, and 1.5% preferred not to answer. Regarding ethnicity, 84.1% were not Hispanic or Latino, 14.3% were Hispanic or Latino, and 1.6% preferred not to answer. Participants received 2 research credits for taking part in the study.

Materials

To ensure the selected colors (red, orange, purple) and odors (berry, orange, grape) represented the expected flavors, informal ratings were gathered from 10 research assistants from the Children's Learning Lab directed by Dr. Helana Girgis at Stockton University. The research assistants were not part of the study, and were asked to identify flavor associations with the colors and odors listed before. Over eighty percent of the research assistants selected expected flavor associations for the colors and odors: cherry, orange, and grape.

Participants were presented with a transparent cup filled up to the second line with sweetened filtered water with half of a packet of Splenda sugar. The liquids were served at room temperature, as changes in taste can occur based on different temperatures on parts of the tongue (Delwiche, 2004). In order to color the filtered Splenda water, food coloring was used from the brand Cherrysea. Four drops of "red" was used for red, four drops of "orange" was used for orange, and two drops of "violet" was used for purple. For the odors, grape essential oil from the brand RainbowAbby, berry fragrance oil from the brand Glade, and orange essential oil from the brand YL was used. To place the odor on the cup, a square white sticker (approximately 1 inch in size) was placed above the water drink line. Three drops of berry oil, three drops of orange oil, and four drops of grape oil were placed onto a q-tip and rubbed onto the sticker.

There were three conditions, a matched condition where color and odor of the expected flavor matched (e.g., purple colored liquid with a grape odor), a single sense condition where only color and no odor or odor and no color was used (e.g., purple colored liquid with no odor, and colorless liquid with a grape odor), and a non-matched condition where color and odor of the expected flavors did not match (e.g., purple colored liquid with an orange odor). See Table 2 for a full list of matched, single sense, and non-matched pairings.

The test questions (dependent variables) were the flavors identified for each drink and the confidence of the flavors identified. For the flavor, participants were asked to take a sip of the sweetened water and write down the flavor they believed the liquid was. A 5- point Likert point likert scale was used to measure confidence from 1(*not very confiden*t) to 5(*very confident*).

Procedure

Each participant received their own order of the 16 trials, which was generated in advance using the website random.org. The procedure commenced as follows: participants arrived at a classroom at Stockton University. Participants sat at a table at the front of the classroom with their back to the door. This was to ensure they did not see the preparation of the drinks and to limit any crossover effect from the odor when preparing the drinks. In order to prepare the materials, all of the colors were added to the drinks before the testing session began. Before each trial was taken to the participant, the odor for that designated trial number was rubbed onto the sticker with the Q-tip to ensure the odor would not fade before the participant sipped the drink. A table was placed outside of the classroom and used to prepare the drinks. A trashcan was placed beside the table with a plastic bag that the used Q-tips were placed in and tied in order to reduce any odor transference.

Each participant was told they would drink 16 different beverages all artificially sweetened with Splenda. After they were done tasting the drink, they were to write down what flavor they perceived the drink to be, and how confident they were in their answer on their datasheet (See Appendix A). After the participants wrote down the flavor and confidence for the drink, the cup was taken back to the table, and the researcher waited 30 seconds before taking the next drink to the participant. A palate cleanser of regular filtered water was used in between each trial. Each participant took about less than 30 minutes to complete the study.

Results

In order to analyze the data, I entered participant responses into an SPSS file. For the non matched trials, responses were coded based on whether participant’s flavor matched the color, the odor, or neither. For example, for the berry odor-orange color drink, berry flavor (e.g., strawberry, berry, blueberry) was coded as odor, orange flavor (e.g., citrus, orange) was coded as color and flavor that was not orange or berry (e.g., gatorade, cotton candy) was coded as neither. The coding system for the single sense trials was based on whether the participant's flavor matched the corresponding odor or color. For example, with a berry odor-colorless drink, berry flavor was coded as odor and flavorless was coded as color. For an odorless-orange color drink, flavorless was coded as odor, and orange flavor was coded as color. For the matched trials, if the flavor response matched the color and odor of the drink, the response was coded with 1. If the response did not match the color and the odor of the drink, it was coded as a 0. For the non-match conditions, counts were created of participants' responses for flavor classification by color, odor, and neither and for the single sense trials, counts were created of participants' responses for flavor classification by color and odor. Afterwards I took the number of times the flavor was classified by odor, color, neither and divided by the number of trials for an average for the non-match trials, and did the same average process for the number of times flavor was classified by odor or color for the single sense trials. For the match condition, the average was calculated for whether flavor matched the color and odor.

In order to examine whether participants perceived the flavor based on odor, color, or neither more often for the non-match conditions, a repeated measures ANOVA was conducted. The results revealed a main effect of sense classification, $F(2,66) = 15.265$, $p < .001$. Follow up analyses using a Tukey's post hoc revealed that odor ($M = 0.21$, $SD = 0.19$, 95% CI of the mean [0.16, 0.25]) was used significantly less for flavor perception than color ($M = 0.41$, $SD = 0.21$, 95% CI of the mean [0.36, 0.47], $p < .001$) and neither ($M = 0.38$, $SD = 0.23$, 95% CI of the mean [0.33, 0.44], $p < .001$). No significant difference was found for using color or neither color and odor on perceived flavor ($p \geq .48$).

In order to investigate potential differences in influence of color and odor on flavor perception for single sense and matched trials, a repeated measures ANOVA was conducted. The results revealed a main effect of sense classification, $F(2,66) = 62.052$, $p < .001$. Follow up analyses using a Tukey's post hoc revealed that for the match condition, participants' flavor matched color and odor significantly more compared to just the single sense odor (M = 0.41, SD = 0.27, 95% CI of the mean [0.35, 0.48], p. < .001), and single sense color (M = 0.29, SD = 0.30, 95% CI of the mean [0.22, 0.37], p < .001). Moreover, for the single sense condition, flavor was significantly more likely to be classified by odor as compared to color ($p \leq .02$).

For the confidence ratings, participants wrote the number for their confidence rating on their datasheet which was inputted into an SPSS file. I calculated the averages of the confidence levels for each of the match trials, non-match trials and single sense trials. In order to investigate if there was any correlation between flavor classifications and confidence levels among the conditions, a Pearson's correlation was conducted. There was a significant positive correlation between the match trials and the match confidence. (r = .31, $p \leq .01$). Participants who reported high confidence with match trials were more likely to select the flavor that matched the color and odor. There was a significant negative correlation between confidence ratings and when flavor matched neither the color or the odor (r = -.29, $p \leq .02$). Participants who reported high confidence with non match trials were less likely to select neither for the non match trials (See Table 3).

Discussion

The goal of this study was to examine if odor or color had a stronger influence on flavor perception. I am not aware of any research that has examined possible differences of the influence of the senses on flavor perception. Importantly, these participants' flavors were based solely on the sensory information as the drinks had no flavor, only sweetened.

It was hypothesized that for the non-match and single sense conditions, odor would be used to classify the flavor more often than color. In addition, I expected flavor perception would match the odor and the color significantly more when two senses were presented for the match condition as compared to only one sense presented in the single sense condition. There was partial support for my hypotheses. Flavor perception matched the color and odor significantly more when two senses were presented for the match condition, and flavor matched odor more often compared to color in the single sense trials. However, for the non-matched trials, flavor perception matched the color of the drink significantly more often than odor.

Regarding the single sense trials, participants used odor to perceive flavor more than color. Rosenblum (2010) explained that 80% of what we taste is due to smell. It is important to note that for the single sense trials, there was only one sense being presented to the participant. They were not experiencing two conflicting senses. Therefore, it could be that when only one sensory cue is presented and participants are trying to perceive the flavor of a drink, smell is the sense that would take over and be the determining factor for the perceived flavor. This may be due to tastants of the drink, activated by taste buds, transmitting messages that overlapped with the areas of the brain activated by the odor of the drink (Small et al., 1999; Poellinger et al., 2001). The taste and smell messages that united helped provide the perception of flavor.

Participants were significantly more likely to match the flavor to both the odor and color when both senses were presented and corresponding with each other in the match condition. This may be due to corresponding sensory inputs from two senses as compared to non-matching or single senses for the other trials. Since both of the senses of vision and odor were representing the same expected flavor, it provided more information about the possible flavor. Confidence ratings support this, as these were higher in the matched conditions compared to the single sense or non matched conditions. It is critical to note that there was no flavor to the drinks themselves, so odor and color were providing enough information to change the flavor from sweetened water to that of berry, orange or grape.

Contrary to expectations, participants used color more to perceive flavor than odor for the non-match trials. One possible explanation for the dominance of the visual cue during flavor perception for the non-match trials may be due to a visual dominance effect. Colavita (1982) found a visual dominance effect when comparing audio and visual stimuli. Participants experienced conditions where they only heard an audio stimulus, only saw a visual stimulus, or experienced a combined audiovisual stimulus. Participants had to press a button if they felt they heard an audio stimulus and press a different button if they felt they saw a visual stimulus. When both of the audio and visual stimuli were presented to the participants at the same time, participants pressed the auditory button significantly less than they pressed the visual button. It supports that when two sensory modalities are presented, at least for vision and audition, vision is the sense that is dominant. Hecht & Reiner (2009) conducted a study similar to the one associated with the Colavita visual dominance effect with similar results. Participants were presented with auditory stimuli, visual stimuli, haptic stimuli, combinations of pairs of those stimuli, as well as all three stimuli presented together, and told to press buttons when they heard, saw or felt the stimuli. Results revealed that when visual stimuli was paired with auditory and haptic stimuli, participants pressed the visual button significantly more often and more quickly than for the other sensory information. Many of the studies that look at the Colavita visual dominance effect include the senses of vision, hearing, and touch. There has not been research testing the effect of odor and vision on flavor perception specifically. Knowing the visual dominance effect exists, perhaps due to the fact that for the non-match trials there were two different senses being presented, vision would rightfully be the sense to take over and override the sensory input of the odor.

As it pertains to the multisensory theory, the results support that not all senses are created equal. The multisensory theory explains that flavor is influenced by all of the five senses, as well as other external environmental cues. However, due to the visual dominance effect that took place during the non-match trials, there could be different influences on flavor perception depending on which sensory cues are being presented and how many sensory cues are being presented at one time. There also could be more complex brain activity during the flavor perception experience especially in the visual cortex area when vision is paired with another sensory stimulus. Furthermore, the findings of this research could be used to aid in enhancing the eating and drinking experience as a whole. If an individual is trying to make drinking water a more enjoyable experience and they only wanted to alter one aspect of it, altering the odor of the water could be the proper single sense effect to influence the flavor perception. Additionally, if there is a meal that already has a set odor cue, an individual could change the color of the food to allow for a potential visual dominance effect to make the flavor perception different and the meal easier to eat.

Limitations

A possible limitation of the study was that open response answers were used for the participants to identify the flavors of the drinks instead of a forced choice response. The open response answers lead to more variability in the data. A forced choice response could have eliminated some variability and kept the responses more centered around those chosen flavors of berry, orange, and grape. However, using an open response option allowed the participants to freely make a choice about what the perceived flavor of the drink was, and did not activate certain expectations to influence flavor. Open choice responses allowed flavor perception to only be influenced by the color or odor. A second possible limitation may have been that the odor of the oil on the stickers was not strong enough, fading slightly between the preparation table to the participant’s table. It may be one explanation for why flavor matched color instead of odor in the nonmatched trials. However, considering the participants’ flavor matching the odor (more than color) in the single sense trials, they were still able to smell it. Lastly, there was a lack of diversity in the sample, which was mostly female and mostly White. Research will need to expand on this before being able to broadly generalize these results.

Further Research

The results of this study provided a foundation for multiple new pathways of research regarding the multisensory theory and the influence of different senses on flavor perception. Not only would future research be useful for replication purposes, it would be useful to examine if there are similar effects of the influences of color and odor on flavor on a wider variety of colors and odors. This study contained two sweet flavors and one citrus flavor, but previous research has shown that irritants, such as spice, can alter the way flavors are perceived. In addition, examining the influence of more than two senses on flavor perception will help further determine the effect of individual senses and explore whether visual dominance applies to flavor perception as well. Further exploration of sensory influence on flavor perception may include investigating if perceived flavor of a beverage with no real flavor, as in my current study, would lead to participants matching the “flavor” of that beverage to a beverage that actually had that flavor. This would examine if the influenced experience of a flavor that was presented in my current study, is of the same effect that a genuine flavor would have on the perception of an individual. Since this is only one study, perhaps there are multiple ways in which senses can conflict with each other and inhibit other senses when it comes to flavor perception, which has yet to be explored.

Conclusion

Flavor perception is a complex phenomenon, one that is influenced by multiple external cues. All of the five senses contribute to the way that an individual experiences and perceives a flavor, but it was unknown whether the strength of each sense differed on changing the perception of flavor. When two corresponding senses were presented, flavor perception was more likely to match the color and odor cues as compared to when only one sense was presented. In the single sense trials, odor was more influential as compared to color. However, when two conflicting sensory inputs were presented, color was more influential than odor for flavor perception. The multisensory theory provides a strong framework in order to investigate why certain senses have the influence that they do, and how new knowledge of the mechanisms of flavor perception can have the potential to enhance a portion of our lives that is necessary for survival.

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Table 1

Color and odor stimuli

Color	Odor	Flavor
Red	Berry	Berry
Purple	Grape	Grape
Orange	Orange	Orange
Colorless	Odorless	No Flavor

Table 2

Matched, Single Sense, and Non-matched Trials

Conditions	Odor	Color
Match		
	Berry	Red
	Grape	Purple
	Orange	Orange
Non-Match		
	Berry	Purple
	Berry	Orange
	Orange	Red
	Orange	Purple
	Grape	Red
	Grape	Orange
Single Sense		
	Berry	Colorless
	Orange	Colorless
	Grape	Colorless
	Odorless	Red
	Odorless	Orange
	Odorless	Purple

Table 3

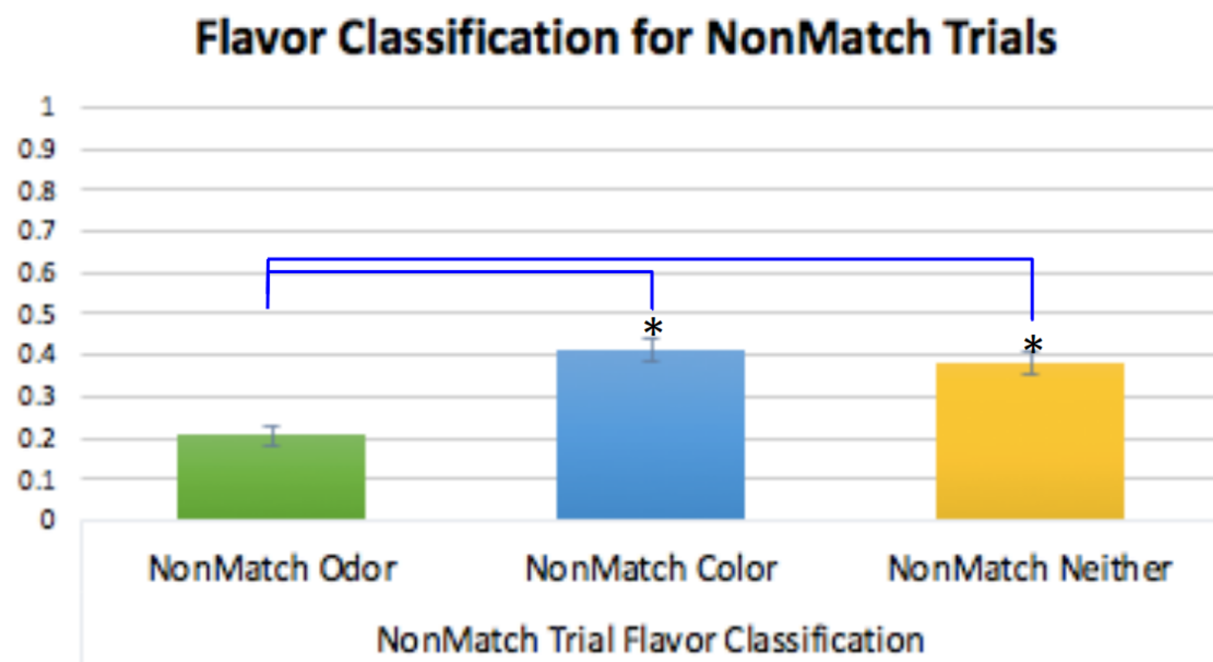
Correlations for Trial Conditions and Confidence

Variable	n	M	SD	1	2	3	4	5	6	7	8	9
1. Match Confidence	68	3.04	0.65	----								
2. NonMatch Confidence	67	2.76	0.62	.438**	----							
3. Single Sense Confidence	68	2.79	0.63	.481**	.560**	----						
4. NonMatch Odor	68	0.21	0.19	.178	.160	.172	----					
5. NonMatch Color	68	0.41	0.21	.090	.172	-.047	-.371**	----				
6. NonMatch Neither	68	0.38	0.23	-.234	-.290*	-.102	-.502**	-.617**	----			
7. Single Sense Odor	68	0.41	0.27	.106	-.023	.038	.477**	-.097	-.288**	----		
8. Single Sense Color	68	0.29	0.30	-.074	.001	-.163	-.060	.406**	-.328**	-.044	----	
9. Match	68	0.71	0.25	.311**	.095	.026	.296*	.206	-.443**	.176	.247*	----

Note. One asterisk (*) is $p < .05$, and two asterisks (**) is $p < .01$. .

Figure 1

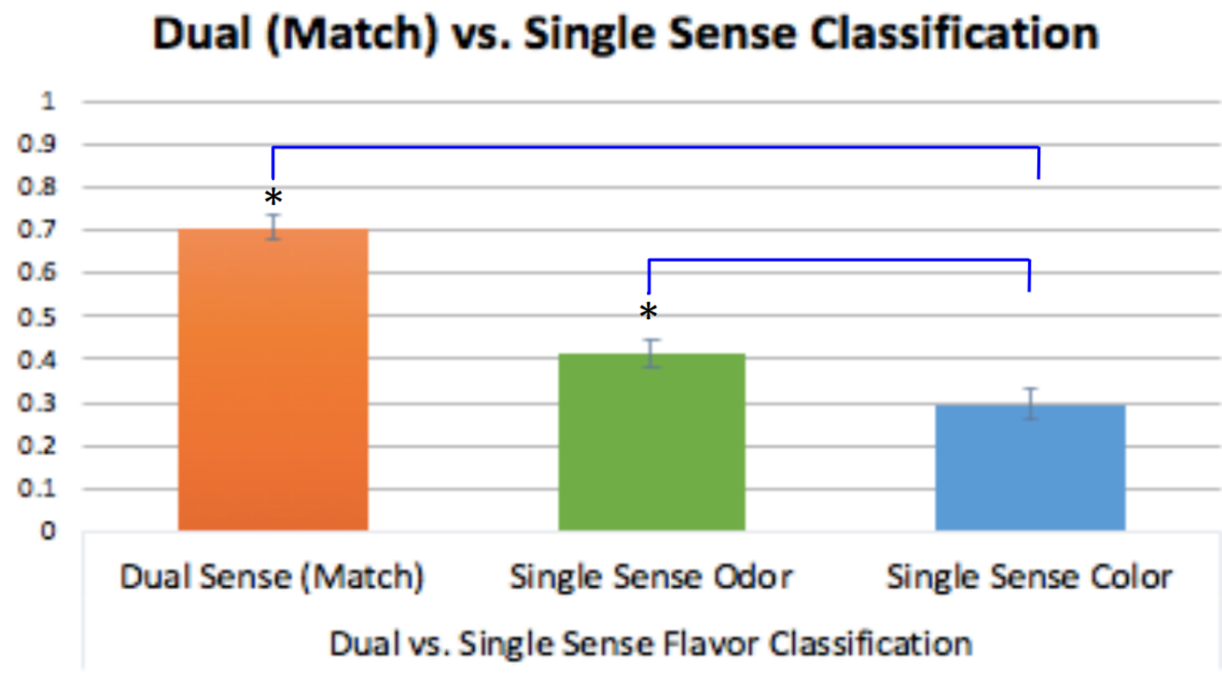
Flavor Classification for Non Match Trials



Note. asterisks (*) imply significant differences at the .05 level sense classification for the non-matched condition. Connector lines indicate which groups are different from one another.

Figure 2

Dual (Match) vs. Single Sense Classification



Note. asterisks (*) imply significant differences at the .05 level between conditions. Connector lines indicate which groups are different from one another.

Appendix A

Trial Number Labels

Each cup of water had a number on the side from 1 to 16 that corresponded with a specific stimuli combination. The labels were as follows:

1) orange odor - orange color
2) cherry odor - purple color
3) odorless - purple color
4) grape odor - colorless
5) orange odor - purple color
6) grape odor - red color
7) odorless - orange color
8) cherry odor - orange color
9) odorless - colorless
10) orange odor - red color
11) grape odor - orange color
12) cherry odor - red color
13) orange odor - colorless
14) odorless - red color
15) grape odor - purple color
16) cherry odor - colorless