Using Olfaction to Prevent Obesity

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ABSTRACT

A longitudinal study manipulated olfactory associations to influence flavor preferences, eating habits and body composition. Pairing seven vegetable odors with nursing during infancy led to enhanced flavor preferences for and increased selection frequencies of those and other vegetables, in addition to healthier body fat percentages, at ages 3 and 20. Infants who experienced vegetable odor-breast milk pairing were also less picky and less neophobic toward paired and extraneous vegetables until at least age 20. Children tend to choose foods with subjectively preferable flavor. Consequently, this study suggests that positive flavor, hedonic and social associations gained from the pairing allowed the vegetable odors to shape the flavor of corresponding vegetables during at least the first encounter, perhaps longer, permitting cascading associative effects and a flavor experience divergent from that of controls. Potentially, the enhanced vegetable flavor led to more frequent selection of the paired vegetables (and fewer unhealthy selections) and, thus, to lower body fat. Positive associations may have generalized to extraneous vegetables, or general pickiness and food neophobia decreased. Given the non-invasive nature of spraying vegetable odors, this investigation puts forth an intervention to reduce the high rate of obesity in America by preventatively targeting unhealthy eating habits.

INTRODUCTION

Poor nutrition often results from unhealthy eating habits and is a primary risk factor for diseases ranging from stroke to obesity. The 2004 Feeding Infants and Toddlers Study found that, in a given 24-hour period, 18 to 33% of 7- to 24-month old children ate no vegetables. A similar proportion of children completely avoided fruits (Fox, Pac, Devaney, & Jankowski, 2004). This is a far cry from the USDA and HHS recommended four to five servings each of fruits and vegetables per day for individuals ages 2 and up ("Dietary Guidelines for Americans," 2011). Such early development of unhealthy eating habits likely contributes to the high obesity rates of 17% and 35% in the American youth and adult populations, respectively (Ogden, Carroll, Kit, & Flegal, 2014). A straightforward approach to mitigating childhood and adult obesity is preventing unhealthy eating habits from forming in toddlers.

Children's food choices depend upon their liking of certain flavors, which in turn, is altered by flavors to which they are exposed during infancy. A 1986 study tested 5- to 13-year-olds and found that how much they liked a food's flavor significantly correlated with how often they chose to eat that food (Michela & Contento). Pickiness and food neophobia are significant factors limiting children from choosing vegetables, and breastfeeding for fewer than six months during infancy predicts pickiness until at least age 7 (Galloway, Lee, & Birch, 2003). This suggests that exposure to myriad flavors in the mother's diet through her breast milk, which is implied by differential suckling behaviors, impacts flavor preferences and food choices later in life (Mennella & Beauchamp, 1991). Furthermore, variety seeking, especially for vegetables, and food neophobia around ages 2 to 3 tend to predict variety seeking until at least age 22, suggesting that early food choices and flavor preferences may influence those later in life (Nicklaus, Boggio, Chabanet, & Issanchou, 2005).

Flavor contributes to how much toddlers like a certain food and therefore to how often they choose it (Beauchamp & Mennella, 2009; Resnicow, Davis-Hearn, Smith, Baranowski, & et al, 1997; Resnicow et al., 1997). Flavor results from a combination of many factors, but smell and taste are its primary constituents (Beauchamp & Mennella, 2009). In flavor, taste and smell are perceived as one, rather than individually, so a change in taste or smell could potentially change the overall flavor percept. Additionally, odorants can acquire the perceptual properties and hedonic value of a taste after temporal association. Studies have found that pairing an odor with sucrose, quinine or citric acid causes the odor to subsequently smell sweeter, more bitter or sourer, respectively (Richard J. Stevenson, Boakes, & Prescott, 1998; Richard J. Stevenson, Prescott, & Boakes, 1995; Yeomans, Mobini, Elliman, Walker, & Stevenson, 2006). For example, since sweetness is, by definition, a type of taste, that caramel odor is considered sweet reflects a property it has acquired from previous associations with sweet tasting caramel. Conversely, the sweeter the odor introduced to a tasted solution, the more it increases the tasted sweetness of the solution; subjects also reported citric acid to taste less sour in the presence of the sweet caramel odor (R. J. Stevenson, 1999). Pairing a disliked or liked taste with an odorant can modulate the rated likability of the odor (Yeomans et al., 2006). Likewise, sweet odors have been found to increase the pleasantness rating of tastes (Schifferstein & Verlegh, 1996). A plethora of literature demonstrates the ability of odorants to both acquire and affect the hedonic and perceptual properties of tastes with which they are paired, manifesting in changes in flavor.

In this longitudinal study, the experimenter investigates whether the experiential interplay between taste, smell and hedonic value can be exploited to shape flavor percepts and thereby to promote healthy eating habits through childhood to adulthood. The scientist pairs vegetable odors with breast milk daily, during the first two months of breastfeeding, so that the vegetable

odors acquire the innately strong hedonic value of breast milk. The vegetable odors may also acquire the savory and sweet characteristics of breast milk, as well as become associated with the rewarding feelings of attachment during nursing. Adult attention paired with presentation of a food (and thus its odor) leads to increased preference for that food for at least 6 weeks (Birch, Zimmerman, & Hind, 1980). Consequently, there is further evidence that the rewarding feelings of attachment paired with the vegetable odors may alter preferences for corresponding vegetables later in life. Control infants are exposed to neutral odors of non-edible items, such as fabric softener and pine. If any of the odors introduced to the control or experimental groups are aversive, previous work indicates that repeated exposure to the odors in the milk flavor should make them less aversive over time, rather than make the infants dislike and avoid the flavor of breast milk (Wardle, Herrera, Cooke, & Gibson, 2003). In cases where the infants do struggle with breastfeeding, their participation is discontinued.

The aim is to give 3-year-olds healthier body fat percentages (BFPs) by causing them to like the flavor of paired vegetables more and thus to choose paired vegetables instead of unhealthy foods more often. If the pairing results in positive associations that last long enough for the vegetable odors to contribute, by altering flavor, to flavor preferences and food choices at age 3, then experimental group toddlers will give a higher average flavor rating to the paired vegetables than will control toddlers. Additionally, the experimental group of toddlers will have a higher average selection frequency of paired vegetables in an assortment of other vegetables and unhealthy foods than will control toddlers. Ideally, experimental group subjects will also have healthier BFPs than will the control group subjects, resulting from the healthier food choices. If the healthy flavor preferences and food choices of the experimental group manifest in sustained healthy eating habits, the experimental group will still demonstrate healthier flavor

preferences, food choices and BFPs during reevaluation at age 20, when food choice is completely free of parental dictation.

MATERIALS AND METHODS

Participants

100 full-term, newborn infants participated with the consent of their parents. Participants were randomly assigned to either the control or experimental group such that each group contained an equal number of males and females. All subjects were breastfed for at least the first two months of life.

Interventional Procedure

During the first two months of nursing, the mother sprayed what was to her an unknown but safe odorant in the air within 5 feet of but not directly over her baby, to prevent liquid from landing on her baby. She sprayed fully once every 5 minutes, for the duration of every one of her infant's nursing sessions. Mothers in both groups had identical spray bottles. They sprayed the same odor on the same day each week. Bottles were labeled according to the day of the week. Mothers wore nose plugs to remain blind to the odorants' identities. Odor spray was produced from an extract or dilution of the odor source such that its smell was detectable by 98% of a group of 25 randomly selected adult males and 25 randomly selected adult females.

Experimental Group*:* Parents sprayed seven different vegetable odors, including odors of kale, broccoli, onion, carrot, pumpkin, radish and sweet potato.

Control Group: Parents sprayed seven different neutral odors of non-edible items, including pine, leather, canary seed, Colgate toothpaste, Purex baby detergent, Nivea cream and grass.

Measures

Measurements were done in the lab at ages 3 and 20 in the same individuals, and the same experimenter performed all measurements. Flavor preferences, food choices and body fat percentages were assessed. The order of assessments performed for each participant was randomized. When evaluating children's flavor preferences and food choices, the experimenter did not provide any input about the different foods. Moreover, parents were asked to leave the room.

The 21 foods about which were inquired were the following.

- Paired vegetables: kale, broccoli, onion, carrot, pumpkin, radish and sweet potato
- Extraneous vegetables: cauliflower, asparagus, peas, corn, spinach, red pepper and potato
- Unhealthy foods: ice cream, pizza, cookies, hamburgers, donuts, pasta and cake

Flavor Preferences: Subjects were presented with questions about 21 foods. No pictures or information about preparation were included.

First, subjects were asked the yes-or-no question: *Have you ever tried ____?*

If they answered "yes," they were asked to check off one of the following:

- ☐ *I really like the flavor of ____.*
- ☐ *I like the flavor of ____.*

- ☐ *I neither like nor dislike the flavor of ____.*
- ☐ *I don't like the flavor of ____.*
- ☐ *I really don't like the flavor of ____.*

Number values were assigned to the statements with -2 corresponding to *I really don't like the flavor of* and 2 corresponding to *I really like the flavor of*. Values increased by 1 with each increment from *I really don't like the flavor of* to *I really like the flavor of*. Experimental and control group means for groups of food were calculated from these numbers. Subjects who checked more than one rating box for a food were excluded. Subjects who said that they had tried a food but did not check a box were also excluded. The order of checkbox statements (ascending or descending) was randomized for each food for each subject. The order of foods was also randomized for each participant. This measurement procedure is very similar to one that had an internal consistency of 0.82 (Resnicow et al., 1997).

Food Choices: Subjects were presented with a list of the 21 foods and instructed to circle the top five foods that they would normally eat. The average number of foods selected from each of the three food groups was calculated for the experimental and control groups. Subjects who did not follow instructions were excluded. The order of the list was randomized for each participant.

***Body Fat Percentage (BFP)*:** The Omron Body Composition Monitor was used to measure subjects' BFPs. The healthiness of each subject's BFP was determined by comparison to her gender-specific, age-specific standard ranges (Jeukendrup & Gleeson, 2010).

DISCUSSION

The pairing of vegetable odors with breast milk resulted in healthier flavor preferences, eating habits and body fat percentages at ages 3 and 20. The experimental group's mean flavor ratings and selection frequencies of both paired and extraneous vegetables were significantly higher than those of the control group. Additionally, significantly more experimental subjects were within the "good" or "athletic" BFP range than were controls, for both males and females. Average flavor ratings of unhealthy foods were not significantly different between the experimental and control groups, whereas the experimental group picked significantly fewer unhealthy foods and significantly more vegetables than did the control group, on average. Such findings imply that, while experimental group subjects still fully appreciated the flavors of unhealthy foods, they liked vegetables' flavors more than did control group subjects and therefore chose vegetables instead of unhealthy foods more often, resulting in healthier BFPs.

Interestingly, the experimental group also exhibited decreased food neophobia for vegetables (fewer *I have never tried* selected, on average) and decreased pickiness for vegetables (fewer *I don't like the flavor of* and *I really don't like the flavor of* selected, on average) at ages 3 and 20. That the experimental group's flavor ratings and selection frequencies were significantly higher than controls' for both paired and extraneous vegetables suggests that pairing vegetable odors with nursing may be helpful in overcoming barriers to liking vegetables in general, consistent with the pickiness and neophobia results. Within the experimental group, the flavor rating and selection frequency of paired vegetables were significantly higher than those of extraneous vegetables, suggesting two possibilities. The paired vegetable odor associations may have been only partially generalized to the extraneous vegetables, which resulted in a less robust flavor enhancement of extraneous vegetables. Alternatively, the associations may not have been

generalized at all, but vegetable neophobia and pickiness were still decreased by another mechanism, perhaps enhanced variety seeking.

That the experimental group's healthier food choices, flavor preferences and BFPs were sustained until at least age 20 suggests that they are associated with vegetable odor pairing, not parental control of diet. Moreover, parents were blind to the identity of the sprayed odors. The sustained effects are consistent with the prediction of eating habits until at least age 22 by those at ages 2 to 3 (Nicklaus et al., 2005). This experiment's findings agree with the idea that the flavors (to which odors, of course, contribute) introduced in breast milk influence eating habits later in life (Galloway et al., 2003). Furthermore, this study presents evidence that vegetable odors can be paired with naturally rewarding and preferred breast milk to shape the selection of vegetables later in life by influencing flavor.

When the infants grew and first encountered the paired vegetables, their natural odors may have (subconsciously) elicited the multisensory memory of the odors' presence during the enjoyment of nursing and the corresponding flavors (Prescott, 2015). Sweet and savory associations and positive associations with nourishment, attachment and pleasurable flavor formed during the pairing, upon recall, may have contributed to enhanced sweet and savory intensity, enhanced hedonic value and suppressed bitterness of the novel paired vegetables (Schifferstein & Verlegh, 1996; Richard J. Stevenson et al., 1998, 1995; R. J. Stevenson, 1999; Yeomans et al., 2006). The positive qualities acquired by the vegetable odors from breast milk pairing may have influenced at least the first flavor experience of the paired vegetables and thus expectations for subsequent experiences. The positive expectations could have contributed to perpetuation or enhancement of the positive associations for both the vegetable odors and flavors.

Multiple scenarios of the role of the vegetable odor associations in subsequent food exploration and flavor explain the healthier flavor preferences and food choices. The hedonic value and other positive associations gained directly from pairing may have remained associated with the vegetable odors and still contributed to flavor at age 3, perhaps beyond. Alternatively, positive associations granted to the paired vegetable odors (and thus to the paired vegetable flavors) as a result of pairing with the breast milk may not have persisted beyond initial encounters with paired vegetables. However, the presence of the positive associations in the first few encounters with the paired vegetables could have induced sufficiently frequent consumption and flavor enjoyment to lead to an independent liking of the paired vegetables' flavors, as repeated exposure to a food tends to increase both liking and consumption (Wardle et al., 2003).

Some could argue that the odors' contributions to vegetable flavor are not the source of the healthier eating habits and flavor preferences. Toddlers with food neophobia tend to be quite reactive to different smells of foods rather than different tastes, suggesting that the smell of novel foods may be that which deters neophobic children from ever consuming them (Monnery-Patris et al., 2015). If this is true, then the acquired hedonic value and other positive associations of what otherwise might have been deterring odors may have reduced the number of paired vegetables rejected by neophobic children and promoted variety seeking, which is reflected by this experiment's findings. In combination with Monnery-Patris et al. (2015), research by Wardle et al. (2003) could imply that the vegetable odors' positive associations led the toddlers to be less opposed to the vegetables upon initial exposures, relative to controls, and the subsequent repeated exposures were responsible for the increases in flavor rating and selection frequency. In other words, this explanation purports that the vegetable odor-breast milk pairing only led to reduced neophobia, and the reduced neophobia then led to increased flavor rating and choosing

of vegetables. Such an interpretation discounts the robust intertwinement of odor with taste and flavor, for odors contribute to flavor both directly and potentially indirectly by forming expectations that influence subsequent flavor experiences. Further studies may investigate whether the role of an odor's associations in flavor preferences and food choices, in this particular case, is truly due to the odor's contribution to flavor, including its contributions to flavor based on expectations before consumption.

Additionally, further studies may examine if the paired vegetable odors merely became more enjoyable due to repeated exposure during infancy, not necessarily due to their introduction in the flavor of breast milk (Wardle et al., 2003). If repeated exposure to vegetable odors is all that is necessary for long-term healthier food choices, flavor preferences and BFPs, then perhaps an intervention that does not require breastfeeding could be performed.

Future work may also study the route by which mean flavor preference for and selection frequency of extraneous vegetables were higher in the experimental group than the control group but lower than those for paired vegetables, within the experimental group. Some may suppose that the paired odors' associations were not even partially generalized and, rather, that the paired vegetables smell very similar to the extraneous vegetables, which led to the significant results for extraneous vegetables. Future research may use two vegetable groups that, upon testing, have no members that smell significantly similar to each other.

If the experimental group's significant flavor preference and selection frequency results for extraneous vegetables were a manifestation of overall decreased food neophobia and pickiness, it is possible that decreased neophobia and pickiness were not seen for unhealthy foods due to a baseline effect. Thus, future research may explore if vegetable odor-breast milk pairing is associated with increased general variety seeking and decreased general food

neophobia and pickiness, manifesting the most in behavior toward the foods readily avoided by children, or if the association is specific to vegetables.

This study shows that pairing vegetable odors with breast milk during nursing results in healthier flavor preferences, food choices and body fat percentage, in addition to decreased pickiness and neophobia for vegetables, until at least age 20. Furthermore, the healthier eating habits are potentially based on greater enjoyment of healthier foods like vegetables. Considering that the overwhelming rates of childhood (17%) and adult (35%) obesity in America have remained stable over 10 years, some intervention should be staged to prevent additional instances of obesity before treatment is necessary (Ogden et al., 2014). While surgical procedures to treat obesity are effective, they are extremely invasive and sometimes result in death (Picot et al., 2009). Spraying vegetable odors during nursing is a simple, non-invasive intervention that should be further explored due to its promising long-term benefits to eating habits, body composition and, by extension, general health.

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