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Insights into smell and taste sensitivity in normal weight and overweight-obese adolescents

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ABSTRACT

Research examining connections between BMI and smell and taste sensitivity in adolescents has been minimal, methodologically inconsistent, and inconclusive. We sought to address this issue with an exploratory study of smell and taste sensitivity in overweight-obese (high BMI) and normal BMI male and female adolescents (ages 12–16 years), using previously validated chemosensory testing measures (Sniffin' Sticks, Taste Strips, 6-*n*-propylthiouracil: PROP), and taking pubertal stage into account. Puberty was evaluated with the validated Pubertal Development Scale and participants were then classified as either "early" or "late" pubertal stage. We used the phenylethyl alcohol (PEA) version of the Sniffin' Sticks olfactory threshold test and found that high BMI adolescents had significantly greater olfactory sensitivity than normal BMI adolescents. This observation contradicts previous results in overweight adults tested with the *n*-butanol version of Sniffin' Sticks. We also found that participants in early puberty had significantly higher olfactory sensitivity than participants in late puberty. No significant findings for taste sensitivity were obtained, though there is a suggestion that puberty may affect salty taste thresholds. Our results illuminate a potentially important difference in sensitivity to pure olfactory versus olfactory-trigeminal stimuli as a function of BMI, which the PEA and *n*-butanol versions of the Sniffin' Sticks respectively assess; and for the first time demonstrate variation in chemosensory acuity in relation to pubertal stage. These findings have implications for eating behavior during adolescence.

1. Introduction

Many factors contribute to an overweight or obese body-mass-index (BMI). However, for most healthy individuals increased caloric intake over energy expenditure is the primary cause for excessive adiposity [50]. The desire for food and associated eating behavior is a multifactorial process involving senses, emotion, psychology, physiology, and environment [21]. Of our senses, taste and smell (the chemical senses) are widely accepted as most directly tied to our experience of food and hence caloric intake. Nevertheless, research examining the association of smell and taste acuity with BMI is rife with mixed results.

In general, findings on the connection between taste perception and BMI have been inconclusive. Some studies testing adults have reported that individuals classified as obese or overweight have reduced taste (salty, sour, sweet, bitter, umami) sensitivity compared to normal BMI participants [4,47,53,55]. However, other studies in adults have shown no effect of BMI on taste sensitivity [18,65], while others have reported that increased BMI is associated with greater taste acuity [20,44]. The specific tastes that show differences in sensitivity between normal and overweight or obese individuals are also inconsistent across studies (see [10]).

Findings for the connection between olfactory sensitivity and BMI are equally variable (see Peng et al., 2018 for review) [46]. In research with adults, several laboratories have reported reduced olfactory sensitivity among overweight or obese individuals compared to healthy weight adults [15,16,19,59,61]. Other researchers, however, have reported that obese individuals have greater olfactory acuity than their normal weight peers [45,59,60]. For example, Stafford and Whittle [60] found that obese male and female college students had higher sensitivity to the odor of chocolate. At least one study reported no differences in olfactory sensitivity as a function of BMI [66].

Methodological and stimuli differences including: variability in subject weight classifications, use of different chemical stimuli, preparations, and concentrations (e.g., in-laboratory formulations,

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commercially available testing materials), and differing response measures (e.g., electrophysiological, psychophysical, behavioral), may account for many of the discrepancies in research examining the relationship between BMI and taste and smell sensitivity. However, other meaningful factors may also be involved. One such factor is the developmental stage of the participants. Given the burgeoning health crises of obesity among children and adolescents [27,31], it is increasingly critical to understand how chemosensory sensitivity interacts with BMI in this younger age group.

Research directly examining the connection of body weight to smell and taste sensitivity in children and adolescents has been sparse. Only one prior study examined BMI in relation to smell sensitivity, and along with testing taste, found that both smell and taste sensitivity were reduced in a sample of obese males and females ages 10–16 years compared to reported norms for that age group [40]. Three previous studies with young participants have addressed taste sensitivity. Overberg et al. [43] tested four concentrations of sour, salty, sweet, bitter, and umami "Taste Strips", and found that umami, bitter, and salty taste sensitivity, as well as 'total taste sensitivity' were lower in obese compared to normal BMI children and adolescents (ages 6–18 years). Feeney et al. [14] tested sensitivity to bitter (PROP), sweet (sucrose), and salty (sodium chloride) in relation to BMI with a large sample of boys and girls aged 7–13; they reported that sweet taste and overall taste sensitivity were lower among overweight/obese males compared to normal weight males. No other statistically meaningful taste sensitivity effects were observed as a function of BMI. By contrast, Pasquet and colleagues [44] using varying dilutions of sucrose and fructose (sweet), citric acid (sour), quinine, PROP (bitter), and sodium chloride (salty) solutions, found that obese adolescent males and females (ages 11.5–17.5 years) had higher sensitivity to sucrose and sodium chloride than non-obese adolescents. In sum, findings concerning the relationship between chemosensory sensitivity and BMI in a young sample have been inconsistent.

It is important to distinguish childhood from adolescence, given the many physiological changes that take place during these developmental phases [1,6,49]. Adolescence is of particular interest because of the profound hormonal changes that occur at this time [6], and the known role that hormones play in smell and taste perception [35,37].

The World Health Organization (WHO) defines adolescence as the age range of 10–19 years (http://www.searo.who.int/entity/child_adolescent/topics/adolescent_health/en/). This nine year span covers a large and variable degree of hormonal development, with some individuals undergoing the pubertal transition much younger than others [51]. Puberty refers to the stages of physiological changes that occur as the neuroendocrine system affects the reproductive system to enable sexual maturity. Developmental researchers generally agree that most individuals between the ages of 12–16 years are in some state of pubertal transition [1]. Our study population was limited to this age range, and we explored pubertal stage in relation to smell and taste sensitivity.

We also examined subject sex in the present research, as sex differences are often observed in chemosensory perception. For example, females are generally reported to have superior olfactory ability than males throughout the lifespan (e.g., [13,42]). Findings for taste are more complex. Nevertheless, it is often reported that females have higher taste sensitivity than males [32].

The goal of our study was to expand upon extant research and investigate smell and taste sensitivity in overweight-obese and healthy weight male and female adolescents. Additionally, though prior work has examined smell and taste function in relation to subject age, and in one case inferred puberty on the basis of age [8], this study is the first to address pubertal stage specifically in relation to chemosensory performance. The paucity and inconsistency of prior findings constrained proposing specific hypotheses, hence our study was exploratory and descriptive in nature.

2. Method

2.1. Participants

Participants were 53 adolescents (24 female; mean age 13.8 years, range 12.4–16.0 years) who participated in a parent study of sleep, circadian timing, and food intake. Participants were pre-screened to be healthy and normally functioning according to a broad range of criteria including: no use of psychoactive substances (confirmed with urine toxicology screening), no first-degree relative with a major psychopathology or genetically transmitted neurological disorder, no evidence of learning disabilities or a physical handicap, and no evidence of chemosensory disorders, confirmed by pre-testing participants for whether they could perceive the strongest concentration of the odor threshold test (all could). All participants were within the normal ranges of the Child Behavior Checklist [2], Youth Self Report [3], and Center for Epidemiological Studies Depression Scale [48]; all had English language proficiency.

Participants were classified as being in a healthy BMI percentile "normal BMI" ($n = 26$) or in an overweight-obese percentile "high BMI" ($n = 27$), based on the CDC's guidelines for Child Weight Status categories of BMI (https://www.cdc.gov/obesity/childhood/defining.html). Normal weight is a BMI percentile within the ≥5th to <85th range, which in our sample ranged from 11.1–83.9. The "high BMI" group comprized a nearly equal number of overweight (BMI in the ≥85th to <95th percentile) and obese participants (BMI ≥ 95th percentile); in our sample the BMI percentile range was 85.6–99.7. No one was in the underweight percentile. To justify combining our overweight and obese participants into one "high BMI" group, we performed independent *t*-tests and found no statistical differences on any measure of smell and taste sensitivity between overweight and obese participants.

Pubertal stage was individually assessed by child report using a modified Pubertal Development Scale [7], where participants report on a variety of physical characteristics, such as "Would you say that your body hair growth?" with response options: *has not yet started (1), has barely started (2), has definitely started (3), seems complete (4), I don't know (missing)*. Responses on the questionnaire are scored to convert to a 1–5 scale score, with 1 indicating that the individual is pre-pubertal and 5 indicating that the individual is post pubertal. This scale has been used in a number of studies and scores are generally comparable to Tanner stages [62] rated by physical examination by health-care professionals. A recent validation analysis of the Pubertal Development Scale [30] indicates that it is most reliable for pre/early puberty scores (1,2), mid-puberty (3), and late/post-puberty scores (4,5). Due to the few subjects we had in pre/early puberty and on the basis of this validation study, we classified our participants into two pubertal groups defined as: "early puberty" (stages 1,2,3; $N = 24$) and "late puberty" (stages 4,5; $N = 28$).

To validate that pubertal stage and age were not identical, we performed a Spearman's *rho* correlation with subject age and pubertal stage, and obtained $r_s = 0.38$, $p < .01$. This demonstrates that our analysis of puberty, though correlated with age as would be expected, offers a unique perspective. See Table 1 for a breakdown of participant characteristics.

This study was approved by the Institutional Review Board for the Protection of Human Subjects of Lifespan Hospitals. Participants were treated in accordance with the Declaration of Helsinki for Medical Research involvement in Human Subjects; parent and participants were compensated for their time. Parental consent and participant assent were obtained.

2.2. Smell and taste test stimuli

To minimize methodological issues, we used validated and commercially available psychophysical tests that did not rely heavily on verbal fluency and that have been previously used with adolescents

Table 1
Participant characteristics.

	Normal BMI	High BMI
N	26	27 (14 obese)
Mean age (± SD)	13.6 (0.9)	14.0 (1.0)
Sex	12 female, 14 male	12 female, 15 male
Pubertal stage	1 = 2 (0 female)	1 = 0
	2 = 5 (1 female)	2 = 2 (0 female)
	3 = 7 (1 female)	3 = 8 (0 female)
	4 = 9 (8 females)	4 = 13 (8 females)
	5 = 3 (2 females)	5 = 4 (4 females)

(e.g., [23,43]). We selected "Sniffin' Sticks" (Burghart GmbH, Wedel, Germany; [24,25,29,63]) for olfactory testing and "Taste Strips" (Burghart GmbH, Wedel, Germany; [39,32]) for taste testing. We also assessed taste with 6-*n*-propylthiouracil (PROP), a standard biological assay to determine taster status (non-taster, taster, supertaster) that has been used as a proxy for taste genotype in many taste studies, including with children (e.g., [5,28,38,58]).

2.3. Olfactory testing

We measured olfactory sensitivity with the Sniffin' Sticks *threshold* test. We also administered Sniffin' Sticks odor *discrimination* and *identification* tests. Sniffin' Sticks are felt-tip pen-like odor-dispensing devices (hereafter referred to as "pen/pens") in which the tampon of the pen is filled with the test odorant diluted in the odorless solvent, propylene glycol.

Threshold testing was performed using 16 concentrations of the target odor phenylethyl alcohol (PEA), which smells like rose. Starting with the lowest concentration of PEA (#16, PEA 0.00000028%), participants were presented with three pens in random order, one containing diluted PEA and two containing propylene glycol (blank controls). Following a standard psychophysical staircase procedure, if the odorized pen was not correctly identified, progressively higher concentration pen sets were presented until correct detection was achieved. When an odorized pen was correctly identified, the same triplet was presented again for confirmation. Two successive correct identifications of the pen containing the odor, or one incorrect identification triggered a reversal of the staircase to the next higher or lower dilution step, respectively. Odor threshold was calculated as the average of four reversals. Higher scores (which correspond to lower threshold) indicate greater olfactory sensitivity.

The *discrimination* test involves 16 triplets of pens, two of which contain the same odor and one that contains a different odor; for each triplet, the participant is asked to indicate the pen that smells different from the other two. The *identification* test includes 16 pens, each containing a familiar odor (e.g., lemon, peppermint, cinnamon). A 4-alternative forced-choice procedure is used for each pen, in which the participant is asked to identify the odor from a list of four descriptors. Higher scores on each test (maximum = 16) indicate better olfactory performance.

For all olfactory testing, the pen cap was removed by the research technician who wore gloves and then waved the pen beneath the participant's nostrils three times. The total time the participant was exposed to each pen was 3–5 s. For odor *threshold* testing, the interval between presentations of individual pens in a triplet was 3–5 s, and presentation of each triplet occurred roughly every 30 s. For both the odor *threshold* and *discrimination* tests participants closed their eyes when odor pens were presented and thus had no visual cues for detecting the target pens. For further details concerning the in-laboratory protocol see Herz et al. [22].

2.4. Taste testing

To determine taste sensitivity with "Taste Strips," we used the standard four concentrations of sweet (0.4, 0.2, 0.1, 0.05 g/ml sucrose), sour (0.3, 0.165, 0.09, 0.05 g/ml citric acid), salty (0.25, 0.1, 0.04, 0.016 g/ml sodium chloride), and bitter (0.006, 0.0024, 0.0009, 0.0004 g/ml quinine-hydrochloride). We did not assess umami because most adolescents perceived umami as salt during pilot testing.

The order of presentation for each of the tastants was randomized across participants. Concentrations of each tastant were always presented in ascending order from lowest to highest. To assess a taste strip, the participant stuck out his/her tongue and the experimenter wearing sterile gloves handed them a strip and told them to place it on the front-center of their tongue. Participants were told to take their time, and with the taste strip on their tongue point to the answer on a sheet that represented their taste perception from the options: "sweet", "sour", "bitter", "salty", "unsure", "no taste", which the experimenter then recorded. Participants were told that some of the strips might be very weak and not to guess, but rather answer "unsure" or "no taste" accordingly. The participant then disposed of the strip and took a sip of bottled water, swished the water around their mouth and swallowed or spit the water into a single-use cup. The start of each taste strip trial was separated by no less than 30 s.

The Taste Strip test was administered multiple times during the parent study. To decrease test time duration and increase efficiency in usage of the taste strips, we did not administer all concentrations of each tastant to every participant at each time, but rather stopped after a minimum of two concentrations as a function of the participant providing two correct responses. During a pilot study, we developed our own administration and scoring method as follows: A score of 1 was given if the first two administrations (concentrations 1 and 2) were correctly identified; a score of 2 was given if the second and third administrations (concentrations 2 and 3) were correctly identified, and concentration 1 was incorrectly identified; a score of 3 was given if concentrations 3 and 4 were correctly identified (concentration 1 may have been answered correctly, but concentration 2 was incorrectly identified); a score of 4 was given if only concentration 4 was correctly identified (there were no prior consecutive correct identifications for that taste); a score of 5 was given if the participant never answered correctly for two consecutive concentrations, and incorrectly identified concentration 4. The lower the score the better the participant's taste sensitivity. In addition to assessing detection to the specific tastants, we evaluated overall taste sensitivity by summing each participant's score on the four tastes (Total Taste Score).

To assess PROP taste perception, PROP was administered as 1.6 mg saturated in filter papers disks that were individually contained in small translucent envelopes. Response sensitivity was measured with the General Labeled Magnitude Scale (gLMS)– a vertical line scale partitioned into numerical increments of 0–100 with six semantic labels (barely detectable, weak, moderate, strong, very strong, strongest imaginable sensation of any kind) fixed at empirically determined points (see Bartoshuk et al., 2004 for details).

2.5. Procedures

The smell and taste sensitivity responses were obtained from the first administrations of the smell and taste threshold tests in the parent study, and were consecutively administered in the late morning. Sniffin' Sticks Discrimination and Identification tests were respectively administered in the early afternoon of the baseline day of the parent study, one day earlier. Participants were also familiarized with the threshold tests on the baseline day. Responses to PROP were obtained at a prior orientation session for the parent study so that the potentially aversive taste of PROP would not interfere with the other chemosensory tests.

2.6. Analyses

Analyses of variance (ANOVAs) on the smell and taste data were performed using STATA (Version 15.1; StataCorp. College Station, TX: StataCorp LP) with weight group (normal BMI, high BMI), pubertal group (early, late), and sex (female, male) as independent variables. Effect sizes for all analyses were calculated using partial eta squared (η^2). We did not have sufficient power to test for interactions, therefore all results are for main effects.

3. Results

3.1. Smell

Three individuals in the early puberty group (2 normal BMI, 1 high BMI) were removed from the *threshold* analysis because they were outliers with abnormally low scores (between 0.5–3), indicating that they had not understood the test instructions. The *discrimination* and *identification* scores for these individuals were within the normal range and included for these analyses.

A main effect of BMI on olfactory *threshold* was obtained, $F(1,45) = 5.5$, $p = .02$ $\eta^2 = 0.29$. High BMI participants had a lower threshold (higher score), thus greater olfactory sensitivity ($M = 10.7$, $SD = 2.7$) than normal BMI participants ($M = 9.4$, $SD = 2.6$). A main effect of pubertal group was also found, $F(1,45) = 5.7$ (1,45), $p = .02$ $\eta^2 = 0.29$, revealing that adolescents in early puberty had greater olfactory sensitivity ($M = 11.0$; $SD = 2.8$) than participants in late puberty ($M = 9.41$, $SD = 5.6$). No statistically reliable sex differences were observed on any of the olfactory tests. See Table 2 for details.

3.2. Taste

No significant effects were observed for responses to PROP. Using the criteria that scores < 20 = non-taster, scores ≥ 20≤70 = taster, and scores ≥ 71 = supertaster, our sample was 22.6% non-taster, 49.1% taster, and 28.3% supertaster, which conforms to typical distributions of taster status in Western populations [5,64]. Our initial analysis of the taste strip data revealed a significant main effect of pubertal group for *salty* taste, $F(1,48) = 4.38$, $p = .04$ $\eta^2 = 0.25$. However, when a correction for multiple comparisons was applied all effects became nonsignificant; the correction changed the p value of puberty for salty to 0.16. With a larger participant sample an effect of puberty on salty taste sensitivity might be obtained. See Table 2.

4. Discussion

4.1. Smell

Adolescents with high BMI percentiles had greater olfactory sensitivity (lower detection threshold) than their normal weight peers. We also found that participants in early puberty had greater olfactory sensitivity than those in late puberty.

Our finding that high BMI participants had greater olfactory sensitivity is at odds with a number of prior studies [15,16,40,59,61]. We used Sniffin' Sticks to measure olfactory acuity in order to maximize methodological validity and replicability; however, there are two versions of the Sniffin' Sticks threshold test. In the original version, concentrations of *n*-butanol are varied; in the newer version used here concentrations of PEA are varied. Reliability tests have shown no statistically significant difference in threshold ability between the two tests in adults ([9]; BMI not accounted for). Nevertheless, the PEA version is considered a better testing method because it lacks trigeminal involvement, in contrast to the strong trigeminal component with *n*-butanol [9]. The trigeminal system is a somatosensory system that stimulates polymodal nociceptors (touch, pain, and temperature receptors) inside the nose and mouth and produces the "feel" of many odors. Importantly, stimulation of the trigeminal system enables detection of the presence of an odorant among people who cannot smell [12]. PEA, unlike *n*-butanol, is among the few odorants that only activates the olfactory system and therefore can assess pure olfactory function.

Examination of the prior research reporting lower olfactory sensitivity among high BMI subjects with the Sniffin' Sticks threshold test, reveals that the *n*-butanol version of the test was administered in all cases ([59,61]; Trellakis et al., 2016; [15,16]). Because we used the non-trigeminal version of the threshold test, our findings suggest that the advantage seen for normal compared to high BMI participants in previous studies may represent compromised trigeminal sensitivity in high BMI individuals, but not compromised olfactory sensitivity. A study by Stafford and Whittle [60] supports this interpretation. They found that high BMI participants had better sensitivity than normal weight participants to the aroma of chocolate. Notably, chocolate aroma does not activate the trigeminal system [56]. Additionally, Obrebowski et al. [40] reported that trigeminally stimulating odors

Table 2.
Means (± SD) for smell and taste measures by BMI group, sex and pubertal group.

SMELL	BMI Group		Sex		Pubertal group	
	Normal	High	Female	Male	Early	Late
Threshold (Maximum = 16)	9.4(2.6)	10.7(2.7)	9.6(2.5)	10.5(2.9)	11.02(2.8)	9.4(2.6)
Discrimination (Maximum = 16)	12.1(2.4)	11.6(2.1)	12.6(1.8)	11.3(2.4)	11.5(2.5)	12.2(2.0)
Identification (Maximum = 16)	12.4(1.6)	11.9(1.8)	12.5(1.6)	11.9(1.8)	12.2(2.0)	12.2(1.4)
TASTE	BMI Group		Sex		Pubertal group	
	Normal	High	Female	Male	Early	Late
PROP (Maximum = 100)	50.4(30.3)	50.8(32.6)	50.8(32.7)	50.4(30.3)	49.3 (32.8)	49.6(29.4)
Sweet (Maximum = 5)	1.6(1.2)	1.5(1.2)	1.6(1.1)	1.6(1.2)	1.7 (1.5)	1.6(1.0)
Sour (Maximum = 5)	2.9(0.8)	2.8(0.7)	2.8(0.6)	2.8(0.9)	2.8(0.8)	2.9(0.7)
Bitter (Maximum = 5)	2.7(1.6)	2.2(1.4)	2.5(1.5)	2.4(1.6)	2.4(1.6)	2.6(1.5)
Salty (Maximum = 5)	1.4(0.8)	2(1.4)	1.7(1.2)	1.7(1.2)	1.4(0.8)	1.9(1.4)
Total Taste Score (Maximum = 20)	8.6(2.9)	8.52(3.1)	8.6(3.0)	9.5(3.0)	8.3(3.2)	9.0(2.8)

Note. For smell and PROP responses higher scores indicate greater sensitivity. For taste strip responses, lower scores indicate greater sensitivity.

elicited lower than normal range detection in obese teens, but that pure olfactory stimuli were less affected by BMI. If impaired sensitivity to trigeminal stimuli explains why those with high BMI do worse on the *n*-butanol version of the Sniffin' Sticks test, then this association combined with greater pure olfactory sensitivity of high BMI individuals may offer a window into how olfactory acuity affects weight gain.

Sweet food odors are generally less trigmeninally stimulating than savory food odors. For example, vanilla and chocolate do not activate the trigeminal system [12,56]. Additionally, sweet food aromas may be especially attractive to adolescents who prefer higher levels of sweetness than adults do [38]. Sweet food aromas may therefore stimulate stronger cravings for sweet foods and consequently increase caloric intake, especially among individuals who are more sensitive to non-trigeminal odorants. At the same time, lower trigeminal sensitivity may make savory foods less intense, which could encourage increased consumption in order to reach satiation [52]. These contrasting chemosensory effects would together make higher BMI more probable. However, it should also be noted that liking for sweet taste is not necessarily linked to higher BMI [26,33].

Tempering the trigeminal conclusion, it is possible that the rose scent of PEA is more pleasant and familiar than *n*-butanol, and that threshold sensitivity may be mediated by these hedonic factors as well. Indeed Seo et al. [54] reported that PEA and *n*-butanol were categorized as pleasant and unpleasant respectively. Hunger state and the perceived edibility of an odor are additional factors to consider, especially when BMI is involved [59]. In future olfactory sensitivity research, trigeminal reactivity will need to be disentangled from other stimulus and individual difference variables.

An alternative explanation for our observation that high BMI participants had greater olfactory sensitivity is that adolescents are simply different from adults with respect to how olfactory sensitivity is affected by BMI. That the adolescence phase does not yield typical olfactory responses is supported by our finding that individuals in early puberty had greater olfactory sensitivity, at least for PEA, than individuals in late puberty. Heightened olfactory sensitivity in early puberty may also affect eating behavior in as yet unexplored ways.

A number of studies have reported that olfactory performance improves through childhood and adolescence, especially for tests requiring verbal processing of odors (see [36] for review). However, at least two studies have shown that age is inversely correlated with odor sensitivity in young subjects [11,57], and a recent large scale study found no differences in olfactory threshold sensitivity across children and adolescents ranging from 6–19 years [17]. It is therefore important that the present study for the first time specifically examined olfactory sensitivity as a function of puberty.

One possibility for the greater sensitivity of early puberty participants is that since they were generally younger, minor chronic nasal conditions (e.g., allergies) may have accrued slightly less of a negative impact than chronic conditions would among older participants. Notably, however, we found that pubertal stage was not equivalent to participant age. Therefore endocrine activity during the pubertal transition may account for our findings.

4.2. Taste

Our taste data did not reveal any statistically significant findings. Nonetheless, our initial (pre multiple comparison correction) observation of an effect of puberty on salty tastes suggests that puberty is a worthwhile variable to consider in future taste sensitivity research. Previous studies have shown overall increases in taste sensitivity as children age to adulthood (see [34] and [67] for review), but a direct examination with puberty has not previously been reported. We expect that with larger sample sizes in future research the role of puberty on taste sensitivity will be clarified.

To our knowledge only one prior study has used the Taste Strips test administered here in an analysis of BMI within a young sample [43]. Contrary to our lack of findings for BMI, Overberg et al. [43] reported that obese participants were less sensitive to salt, as well as umami and bitter. They also found that older age and female sex were associated with greater taste sensitivity. We did not observe any sex differences, which adds to the mixed results for sex in younger samples reported in the chemosensory literature (for example: [14,28,41,42,44,57]). Methodological discrepancies between the present study and Overberg et al. [43] where a larger sample of participants encompassing a wider age range (6–18 years) were tested, may also account for the differences.

It is intriguing to consider that taste sensitivity differences between high and normal BMI individuals may vary in relation to trigeminal versus non-trigeminal stimuli, which Taste Strips do not assess. A test of sensitivity to a pure trigeminal tastant, such as capsaicin, could address this issue.

4.3. Limitations

Our study was limited by a relatively small sample size due to the constraints on subject recruitment and demands of the parent study, and as such we did not have the power to test for interactions among our independent variables. We also did not directly compare the *n*-butanol and PEA versions of the Sniffin' Sticks threshold test, and as such our conclusions concerning the differences between trigeminal and olfactory function are provisional. Finally, our assessment of pubertal stage was descriptive, and we did not have any direct measures to identify whether specific hormonal or other physical changes are involved in our findings. Nonetheless, as an exploratory study, our findings illuminate potentially important factors underlying BMI and chemosensory sensitivity in adolescents.

5. Conclusions

In this exploratory and descriptive study we observed that adolescents with a high BMI had greater sensitivity to a pure olfactory stimulus than adolescents with a normal BMI. We also found that adolescents in early puberty had greater odor sensitivity than adolescents in late puberty. Our findings add to the limited literature on BMI and the chemical senses in adolescence, and offer novel insights into how pubertal stage and different dimensions of chemosensory function may be related to these observations. These findings have ramifications for future research methodology, and more broadly may have important implications for food consumption during adolescence.

Extrapolating our findings to food consumption suggests that heightened sensitivity to non-trigeminal odors could increase detection and appetitive responses to food aromas that are not trigeminally activating (e.g., sweet foods), making it more likely that these foods will be consumed. That this heightened sensitivity is especially evident in early puberty, when impulse control and knowledge of caloric and health attributes of foods are typically not well developed, adds to the risk for non-nutritious eating and weight gain. If our speculations are validated with future research, providing information on potential food-aroma vulnerabilities may help adolescents who struggle with weight to better navigate their food environment.

With regard to methodology, our study underscores the utility of using validated and replicable chemosensory testing measures. More importantly, the present findings indicate that future research should consider trigeminal and other hedonic qualities of the stimuli that are administered to assess chemosensory function, and that in young cohorts pubertal stage, not merely age, should be evaluated in relation to the observations. Ideally, future research building on our results, should evaluate chemosensory responses in relation to actual food preferences and consumption, especially for sweet, salty and spicy foods.

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