The development of basic taste sensitivity and preferences in children

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Abstract

This study aims at understanding how preference and sensitivity to the basic tastes develop in the preschool years, and how the two relate to each other. To expand on the existing literature regarding taste preferences conducted in cross-sectional studies, a longitudinal design was applied with children from age four to six years old.

During the springs of 2015, 2016, and 2017, 131 children born in 2011 were tested in their kindergartens. To investigate preferences for sweet, sour and bitter tastes, the children performed ranking-by-elimination procedures on fruit-flavored beverages and chocolates with three taste intensity levels. The beverages varied in either sucrose, citric acid, or the bitter component isolone. The chocolates varied in the bitter component theobromine from cocoa and sucrose content. Each year, the children also performed paired-comparison tasks opposing plain water to tastant dilutions at four concentrations. The stimuli consisted of the five basic tastes: sweet (sucrose) sour (citric acid monohydrate) umami (monosodium glutamate), salty (sodium chloride), and bitter (quinine hydrochloride dihydrate).
Preference for sweetness levels increased with age, while preference for bitterness and sourness levels were stable. Concerning taste sensitivity, the children showed an increase in sensitivity for sourness and saltiness, a decrease for sweetness, and stability for umami and bitterness. A negative association was found between sweetness sensitivity and preference for sweetness. The study highlights different trajectories of sensitivity and preferences across tastes. On average, a reduction in sweetness sensitivity combined with an increase in preference for higher sweetness was observed from the age of four to six. The weak relationship between taste sensitivity and taste preference in our data suggests that taste preference development is shaped by a multitude of factors in addition to taste sensitivity.

Keywords: Taste; sensitivity; preference; children; longitudinal; sweet; bitter; sour

1. Introduction

Taste preferences are an important determinant for the actual food choices of children. Higher sweet taste preference is associated with higher consumption of sweet foods (Liem & Mennella, 2002; Mennella, Finkbeiner, & Reed, 2012; Mennella, Reed, Mathew, Roberts, & Mansfield, 2014) and overweight in children (Lanfer et al., 2013). In addition, a higher preference for sour taste has been associated with the consumption of fruit (Blossfeld et al., 2007; Liem, Bogers, Dagnelie, & de Graaf, 2006), and acceptance of sour fruit and vegetables (Schwartz, Chabanet, Lange, Issanchou, & Nicklaus, 2011). Bitter taste perception has been related to acceptance of some vegetables (Keller, Steinmann, Nurse, & Tepper, 2002; Turnbull & Matisoo-Smith, 2002). Understanding taste preferences in children can help in encouraging a healthier palate with higher consumption of fruits (sweet and sour tastes) and vegetables (sour and bitter tastes).

Several factors influence taste preferences, among others culture (Lanfer et al., 2013), genetics (Fildes et al., 2014), repeated exposure (Beauchamp & Moran, 1984; Liem & De Graaf, 2004), and role models such as parents and siblings (Benton, 2004). Additionally, as investigated in this paper, taste preferences can change over the first years of life (Schwartz et al., 2017). For sweetness, the preferences are stronger in childhood than in adulthood (Lawless, 1985; Pepino & Mennella, 2005; Zandstra & de Graaf, 1998), but less is known regarding the development within the preschool years. An increase in sweet taste preference through the preschool years has been reported (Cooke & Wardle, 2005; Lanfer et al., 2013), but this observation is not systematic, wherease no significant difference in sweet taste preference was observed between 4 and 5-year olds (Liem, Mars, & De Graaf, 2004b). The same tendency is found for sour taste preferences, with about a third of children having a distinctly higher sourness taste preference than their mothers (Liem & Mennella, 2003), but with no age-effect within the span from age five to nine (Liem & Mennella, 2003) nor age seven to 12 years old (Liem, Westerbeek, Wolterink, Kok, & De Graaf, 2004). For bitter taste, a longitudinal study found stability in acceptance between the age of three and twenty months (Schwartz et al., 2017), but little is known regarding later development. However, except for one study (Schwartz et al., 2017), the above-mentioned studies are all cross-sectional, and more insight is needed from longitudinal data. The present study therefore investigated taste preferences during the three last years of kindergarten (4-6 years of age in Norway), which has previously not been investigated.

An additional factor influencing taste preferences in children could be taste sensitivity. Taste sensitivity can be expressed as the ability to perceive a taste, and is by some theorised to be a determinant of preferences for the basic tastes (Lanfer et al., 2013), but others argue that the association is of small amplitude, as studies are few and the relationship found weak or non-existent, both in children (Lanfer et al., 2013; Liem, Westerbeek, et al., 2004), adolescents (Coldwell, Oswald, & Reed, 2009) and adults (Mojet, Christ-Hazelhof, & Heidema, 2005). Across tastes, sensitivity for the bitter agent quinine has been associated with a preference for higher sucrose intensities in adults (Duffy, Peterson, Dinehart, & Bartoshuk, 2003; Hayes & Duffy, 2008), but hasn't been investigated in preschoolers. Taste sensitivity has previously been found to undergo development during the preschool years, in particular for sweetness. Sucrose sensitivity increases within the preschool and childhood years (Joseph, Reed, & Mennella, 2016; Visser, Kroeze, Kamps, & Bijleveld, 2000), continuing into adulthood (De Graaf & Zandstra, 1999). For bitter taste, no clear developmental trends have been established (Visser et al., 2000). To our knowledge, the same is true for sourness, saltiness (Bobowski & Mennella, 2015; Knof, Lanfer, Bildstein, Buchecker, & Hilz, 2011; Lanfer et al., 2013), and umami (Bobowski & Mennella, 2015; Knof et al., 2011; Lanfer et al., 2013). Among other reasons, this is because of the difficulty in studying taste sensitivity with the youngest children. Several studies have not been able to validate methods for four-year olds (Liem, Mars, & De Graaf, 2004a) or children under the age of six (Knof et al., 2011). An additional issue is that none of the above-cited studies are longitudinal. Overall, the development of taste sensitivity and preferences in preschool years is still vastly unknown for all the different basic tastes.

This paper uses a longitudinal design to investigate the development of preferences for sweet, sour, and bitter taste between the ages of four and six years old, and whether these preferences are associated with sensitivity for the basic tastes. This paper also reports on the development of basic taste sensitivity for sweet, sour, bitter, salty and umami within the preschool years.

2. Method

2.1. Study overview

The data ~~was~~ were collected longitudinally. Children born in 2011 were tested in their usual kindergartens yearly in 2015, 2016, and 2017, i.e. from the year they turned four to the year they turned six. The children were recruited in 18 different kindergartens in the eastern part of

Norway. One hundred and fifty-one children participated in total, with 131 participating all three years. Fifty-eight percent were boys. Written parental consent was necessary to enrol in the study, as well as verbal agreement by the child at the beginning of each session. The study protocol was approved by the ethical committee of the Norwegian Center for Research Data. Further details have been reported in Vennerød, Almli, Berget, and Lien (2017)

Each year, the children participated in the same program, divided into four weekly visits from the experimenters. The first visit aimed at familiarising the children to the experimenters. The second and the third sessions consisted of taste sensitivity testing, always in the same order for all tastes: first sensitivity to sweet, sour, and umami, then a week later, to salt and bitter taste stimuli. The fourth session investigated preferences for sweetness, sourness, and bitterness, in non-carbonated soft drinks and dark chocolate. The first year (2015), eight randomly selected kindergartens with 46 children participated in a fifth session consisting of a retest of either the sensitivity or the preference test (Vennerød, Almli, et al., 2017).

Careful considerations have to be taken when doing sensory research with children (Laureati, Pagliarini, Toschi, & Monteleone, 2015; Nicklaus, 2015). In this study, several actions were employed to facilitate the children's participation. Particularly, tests were designed to lessen the impact of cognitive differences, both between the children, and during the timespan of the study. The tests were therefore non-verbal for the children's part, and included several elements of gamification.

To investigate differences in cognitive development within the sample, the validated Norwegian version of the Ages and Stages Questionnaire (ASQ) was used (Janson & Squires, 2004; Richter & Janson, 2007; Squires, Potter, & Bricker, 1999). The ASQ measures children's cognitive development in five areas: communication, fine and gross motor, personal-social, and problem-solving skills, and allows deriving a global cognitive development status score. The questionnaire evolves with the age of the child; each year, the parents received the appropriate questionnaire according to the age of the child. The ASQ scores revealed that the vast majority of the sample had developed the minimum skills expected for their age at each year (92.9% at age four, 94.2% at age five, and 96.4% at age six).

2.2. Sensitivity testing

Taste sensitivity sessions were conducted on five basic tastes with the children. The stimuli consisted in four levels of water dilutions; see Table 1 for concentrations. The children performed a discrimination task in a paired comparison procedure successively opposing plain water to the tastant dilutions, in 20 ml servings. In order to rely on affect rather than analytical processes, which are not fully developed at this young age, children were told that the cups might contain “magic water”, which would taste differently from regular water. The children were asked to identify the “magic water” in each pair, and sort the cups on to the corresponding place mats (either picture of magical character for magic water, or picture of water drop for plain water). The stimuli were always presented from the strongest concentration (D3) to the weakest one (D6). A more thorough description of the procedure can be found in Vennerød, Hersleth, and colleagues (2017).

Table 1: *Taste dilutions presented against plain water in paired comparison tests. For each basic test, dilutions were always presented from the strongest concentration (D3) to the weakest (D6)*

Basic taste [a]	Taste compound	D3 (g/l)	D4 (g/l)	D5 (g/l)	D6 (g/l)
Sweet	Sucrose	4.32	2.59	1.56	0.94
Sour	Citric acid monohydrate	0.38	0.31	0.25	0.20
Umami	Monosodium glutamate	0.49	0.34	0.24	0.17
Salty	Sodium chloride	0.98	0.69	0.48	0.34
Bitter	Quinine hydrochloride dihydrate	0.0038	0.0023	0.0017	0.0014

[a] All compounds and dilutions correspond to D3-D6 from the ISO-standard 3972 (ISO, 2011), except for bitter taste. For bitter, quinine dilutions are based on Hartvig (2013) and Allesen-Holm and Gadegaard (2009).

2.3. Preference testing

2.3.1.Taste carriers

Taste preferences were measured for sweet, sour, and bitter stimuli, each at three intensity levels. Sample development was based on sensory descriptive analysis (ISO 13299-2003) by a trained sensory panel of 11 assessors, and aimed at ensuring a systematic variation at three levels for each target basic taste in the selected sample triads. The taste carriers of the preference test were fruit-flavoured beverages and chocolate, to cover both liquid and solid matrices. Three beverages with different levels of sugar content (4% vs 12% vs 18%) were selected, characterised by large significant variations in sweetness in the sensory description. In addition to sweetness, the sweet drinks showed significant differences on sour taste, astringency, richness, cloying flavour, and to a lower extent on flavour intensity (Figure 1B). The three ~~sour~~ beverages modified in sour taste all contained 8% sugar, and differed in level of citric acid (0.13% vs. 0.21%. vs. 0.35%). In addition to sourness, significant differences were found in flavour intensity, astringency, fruit flavour, and to a lower extent on artificial flavour and odour, mouth coating and sweet taste (Figure 1D). For bitter drinks, the level of isolone differed from 0.001% to 0.002% to 0.003%. Isolone is a purified isohumolone converted from hop alpha acids. In addition to bitterness, significant differences were found in flavour intensity, astringency, pungency, and to a lower extent on mouth coating and cloying flavour (Figure 1C). The dark chocolates varied in cocoa content (45% vs. 55%. vs 65%), but also in sugar content (53% vs. 42% vs. 32%, respectively), and significantly differed on both bitterness and sweetness (Figure 1A). Note that despite otherwise equivalent recipes, the samples also differed in both odour and flavour for cocoa, vanilla, tobacco, milk and caramel, as well as in astringency, meltability, hardness and smoothness (Figure 1A). The Norwegian company Orkla Foods Norge produced all beverage and chocolate samples especially for the present study.

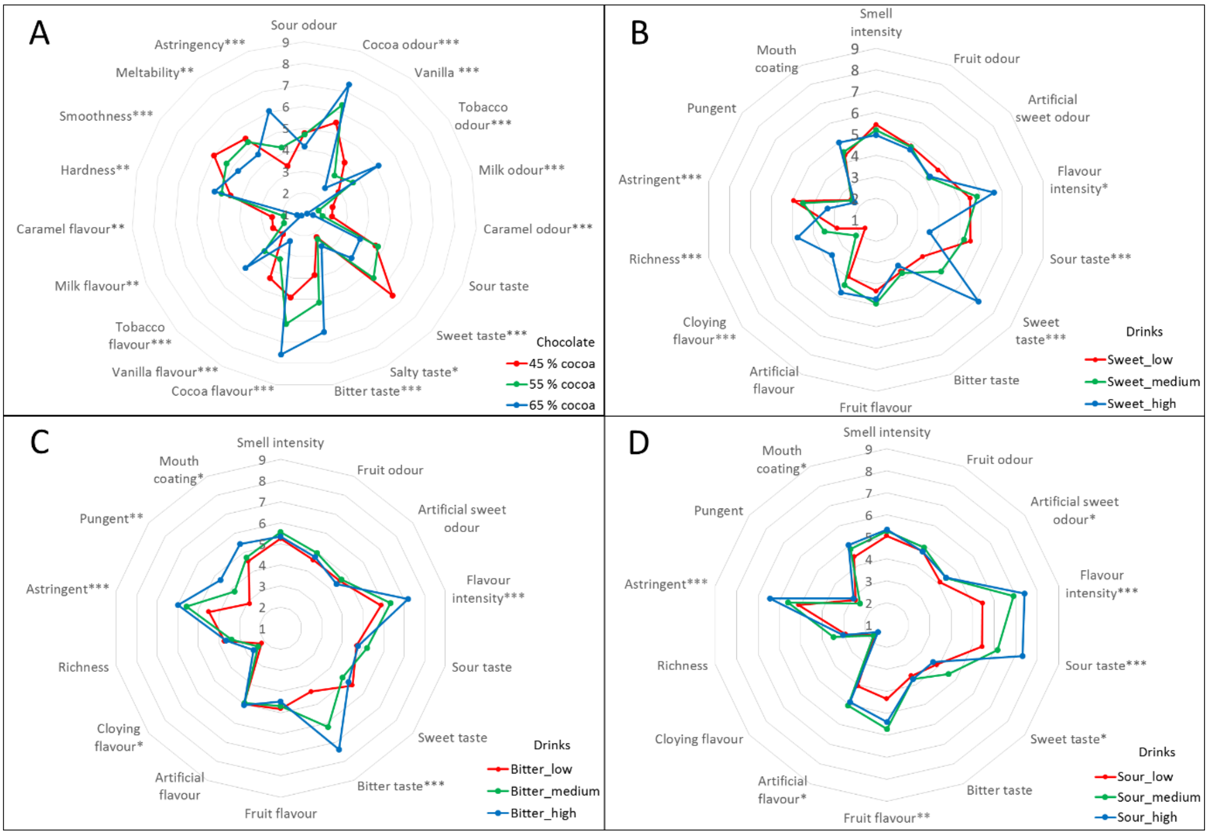

Figure 1: Sensory description obtained by a trained panel of the selected taste carriers in preference testing. A/ Chocolates, B/ Sweet drinks, C/ Bitter drinks, and D/ Sour drinks. Stars indicate attributes with significant differences at $p<0.05^{*}$, $p<0.01^{**}$ and $p<0.001^{***}$.

2.3.2. Protocol

To engage the children more, ~~The~~they ~~children~~ were told that it was Teddy Bear's birthday, and asked to suggest ~~the best~~ their best liked samples for his birthday party. They then performed ranking-by-elimination procedures on the different drinks and chocolates. They were presented with a sample triad (e.g. the three drinks varying in sour taste intensity), and asked to choose the ~~best~~ one they liked best. This one was removed, and the child was again asked to choose the best liked sample of the remaining two, thus providing a ranking. The presentation order of the triads and samples was randomized across children, and testing occurred in a double-blind condition as the interviewer did not know which sample the child tested at any time. After the three preference tests on drinks (sweet, sour and bitter taste variations), three pieces of chocolate (bitterness/sweetness variation) were placed in front of the child and the same ranking by elimination procedure was repeated for the chocolate. The drinks were served at room temperature, with 10 ml per sample, and the chocolates were offered in two small pieces per sample (about 4.5 g per total serving). See Vennerød, Almli and colleagues (2017) for a full description of the procedure.

2.4. Sensitivity and preference scores

The sensitivity score is calculated using correct answers. Correct answers were scored based on the children's performance in the discrimination task, and the indicator is therefore an interval score from 0 (no discrimination in the pair of the strongest tastant) to 4 (correct detection of the tastant in all four pairs). A pair was only attributed a hit score if all previous pairs (higher concentrations of the same basic taste) were a hit. The score is calculated using the *Child Scoring Criterion* (CSC), where the assignment of the strongest concentration sample (taste dilution D3) as either magic or plain water defines the blueprint for this basic taste for this child throughout the procedure, as exposed with full details elsewhere (Vennerød, Hersleth, Nicklaus, & Almli, 2017). As "magic water" is an abstract term, the child thus decides its own criterion for which cup should be labelled as magic, and has to be consistent with this labelling.

The preference score is calculated by multiplying the rank of each sample (1, 2 or 3, where a higher rank codes for a higher preference) with the strength of tastant in the sample (1, 2 or 3, where a higher strength codes for a higher taste concentration). The calculated scores for all samples within a taste are then added together, and the preference scores obtained may thus vary from 10 to 14. The scores are then transformed to an interval-scale ranging between 1 and 4, inspired by Liem, Mars, et al. (2004a). As an example, if the sweetest drink was the most preferred, the middle drink the second preferred, and the least sweet drink the least preferred, the raw preference score would be computed as 3*3 + 2*2 + 1*1 = 14, and then transformed to a 4 in the interval-scale. A higher score corresponds to a preference for more intense drinks.

2.5. Data analyses

Data analyses were run with children that had completed all the tests for a given taste during the timespan of the study. This differed from 92 children for preference in chocolate to 124 children for preference in sweet drinks.

To evaluate the potential impact of developmental differences on sensitivity or preference between the children within each year, Pearson product-moment correlation coefficients were calculated, using ASQ-scores and either preference or sensitivity score.

To investigate how taste preferences developed over the years, four repeated measures analyses of variance (ANOVA) using preference score were run separately for sweet, sour, or bitter drinks, or chocolate. If a significant difference was revealed, three paired samples t-tests were employed to make post hoc comparisons between years, using a significance level of 0.05. To investigate preference development at individual level, the children were grouped into six preference development profiles. The children were only grouped in one group each. Three of the groups included children that were stable in their preference: “~~Low preference~~Preference for low intensities” includes children that had the two lowest preferences ~~scores~~ for all years (1 all years or 1 combined with ~~and~~ 2), and thus preferred low intensities. “~~Medium~~ Preference for medium intensities~~preference~~” includes children that had the two medium ~~scores~~ preferences (2 or, ~~and~~ 3 all years, or a combination of the two), and “~~high~~ Preference for high intensities~~preference~~” the two highest (4 all years, or 4 combined with 3~~3 and 4~~). Two of the groups included children that had a change in preference: “Increase” corresponds to at least two points higher at age six than at age four, and “decrease” to at least two points lower at age six than at age four. The score at age five had to fit with the trend – i.e. not diverge from increase or decrease, accordingly. The group “other” corresponds to all other development patterns.

Five repeated measures ANOVAs were run separately, investigating if there was a change in sensitivity for each basic taste (i.e. sweet, sour, bitter, umami or salty) over the three years. If a significant difference was revealed, three paired samples t-tests were employed to make post hoc comparisons between years, using a significance level of 0.05. To investigate sensitivity development at individual level, the children were grouped into six sensitivity development profiles. Three of the groups included children that were stable in their ~~preference~~sensitivity: "Low sensitivity" includes children that had the two lowest scores for all years (0 and 1). "Medium sensitivity" includes children that had the two medium scores (either 1 and 2, or 2 and 3), and "high sensitivity" the two highest (3 and 4). Two of the groups included children that had a change in sensitivity: "Increase" corresponds to at least two points higher at age six than at age four. "Decrease" to at least two points lower at age six than at age four. The score at age five had to fit with the trend – i.e. not diverge from increase or decrease, accordingly. The group "other" corresponds to all other development patterns.

In addition, Kendall tau-b correlation coefficients were calculated to investigate if there was a correlation between preference and sensitivity.

3. Results

3.1. Cognitive development effects

The investigation of potential developmental effects revealed that there was no correlation between cognitive development (ASQ-score) and taste sensitivity or preference score at any year. Similar tests were run for each sub-dimension of the ASQ, and did not reveal significant differences. Thus, individual differences observed in sensitivity and preference scores were not due to differences in cognitive development level.

3.2. Development of preferences

Age had a statistically significant effect on sweetness preference $F(2,124)=5.437$, $p=.005$. Paired samples t-tests revealed that there was a significant increase in sweet preference between the age of four (M=2.8, SD=1.1) and six (M=3.4, SD=.88), $t(123)=-3.946$, $p<.001$, Cohen's $d=0.60$, and five (M=3.2, SD=.97) and six, $t(123)=-1.725$, $p=.048$, Cohen's $d=0.21$. No difference was revealed between the age of four and five, $t(123)=-1.033$, $p=.304$, Cohen's $d=0.40$. There was no effect of ~~development~~ age on preferences for neither sourness $F(2,120)=.560$, $p=.572$, nor bitterness $F(2,120)=.393$, $p=.676$ in beverages. The mean scores during all three years can be seen in Figure 2. There was a statistically significant effect of ~~development~~ age on chocolate preference, F(2,92)=3.109, p=.048. Paired samples t-tests revealed that there was a significant difference between the age of four (M=2.8, SD=.81) and six (M=2.24, SD=.96), t(91)=2.503, p=.014, Cohen's *d*=0.57, with a decrease in preference for higher levels of cocoa, corresponding to less bitter and sweeter taste. No difference was revealed between neither the age of four and five (M=2.5, SD=1.13), t(91)=1.229, p=.222, Cohen's *d*=0.03, nor the age of five and six, t(91)=1.508, p=.135, Cohen's *d*=0.02.

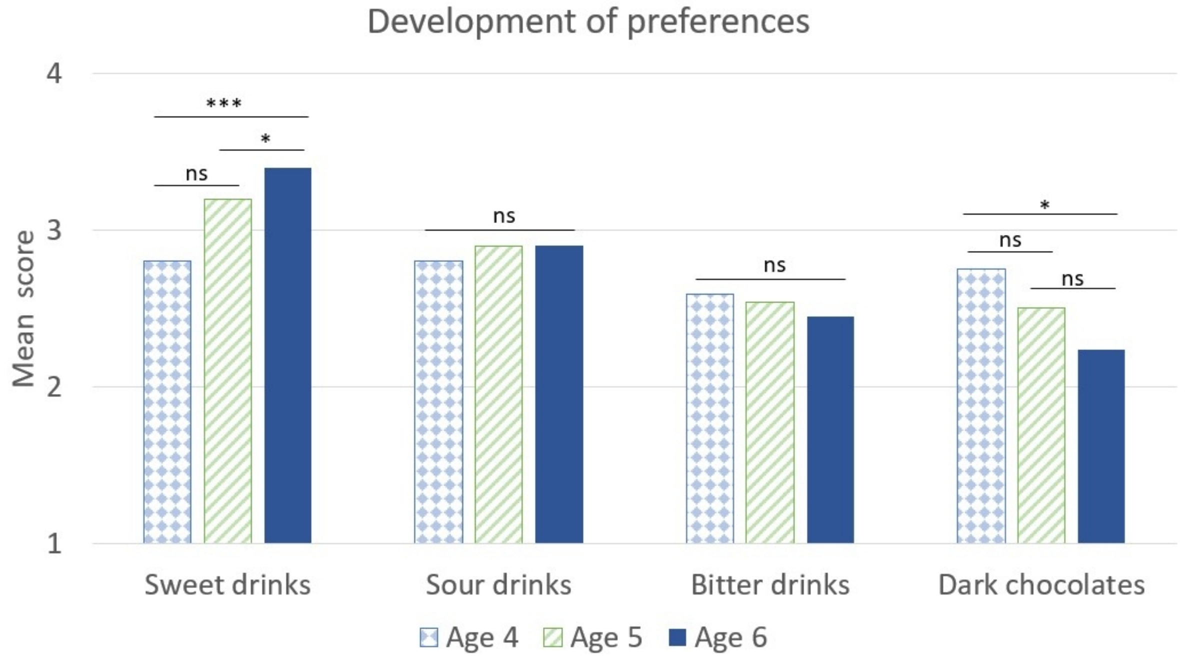

Figure 2: The development of preferences for sweet, sour, and bitter drinks, and chocolate, using mean scores for each sample triad per year. Comparison of ages four (beams with diamonds), five (striped beams), and six years old (solid beams). Stars indicate significant differences at $p<0.05^{*}$ and $p<0.001^{***}$.

The individual preference development profiles indicate that children overall had a stable medium or high preference for sourness (68.5%), stable low, medium or high preference for bitterness (76.1%), either medium/high preference (57.8%) or increase (20.3%) for sweetness (Table 2). No overall trend for chocolate.

Table 2: Percentages of children in each preference development profile

	Stable low [a]	Stable medium [b]	Stable high [c]	Increase [d]	Decrease [e]	Other [f]
Sour (beverages)	12.1%	38.0%	30.5%	9.7%	4.3%	5.4%

Sweet (beverages)	4.5%	18.0%	39.8%	20.3%	6.1%	11.3%
Bitter (beverages)	16.1%	40.3%	19.7%	5.6%	8.9%	9.4%
Chocolate	14.2%	26.6%	11.7%	13.3%	25.0%	9.2%

[a] Lowest or second lowest score for all years, [b] The two middle scores for all years, [c] Highest or second highest score for all years, [d] At least two points higher on score at age six than at age four, [e] At least two points lower at age six than at age four, [f] all other development patterns

3.3. Development of sensitivity

Age had a statistically significant effect on sensitivity for sweetness F(2,113)=11.925, p<.001. Paired samples t-test revealed a significant decrease in sensitivity score from age four (M=1.82, SD=1.31) to age five (M=1.51, SD=1.32), t(112)=3.396, p=.001, Cohen's *d*=0.24 from age four to age six (M=1.04, SD=1.18), t(112)=4.615, p<.001, Cohen's *d*=0.62 and from age five to age six, t(112)=2.45, p=.016, Cohen's *d*=0.37.

In addition, a significant effect of age on sour sensitivity was found F(2,112)=3.109, p=.048. Paired samples t-test revealed a significant increase in sensitivity score from the age of four (M=2.77, SD=1.40) to the age of five (M=3.20, SD=1.38), t(111)=-1.995, p=.049, Cohen's *d*=0.36, and from age four to age six (M=3.38, SD=1.12), t(111)=-2.317, p=.023, Cohen's *d*=0.55, but not from age five to six t(111)p=.211, Cohen's *d*=0.15.

For saltiness, a significant effect of age was revealed, F(2,125)=6.918, p=.001. Paired samples t-test revealed a significant increase in sensitivity score from age four (M=2.21, SD=1.26) to age five (M=2.43, SD=1.28), t(124)=-4.546, p<.001, Cohen's *d*=0.15 and age four to age six (M=2.32, SD=1.30), t(124)=2.702, p=.048, Cohen's *d*=0.08. No difference was found between the age of five and six, t(124)=1.56, p=1.22, Cohen's *d*=0.07.

There was no effect of age for neither bitterness, F(2,125)=.534, p=587, nor umami taste, F(2,110)=. 1.372, p=.257.

The mean scores during all three years can be found in Figure 3.

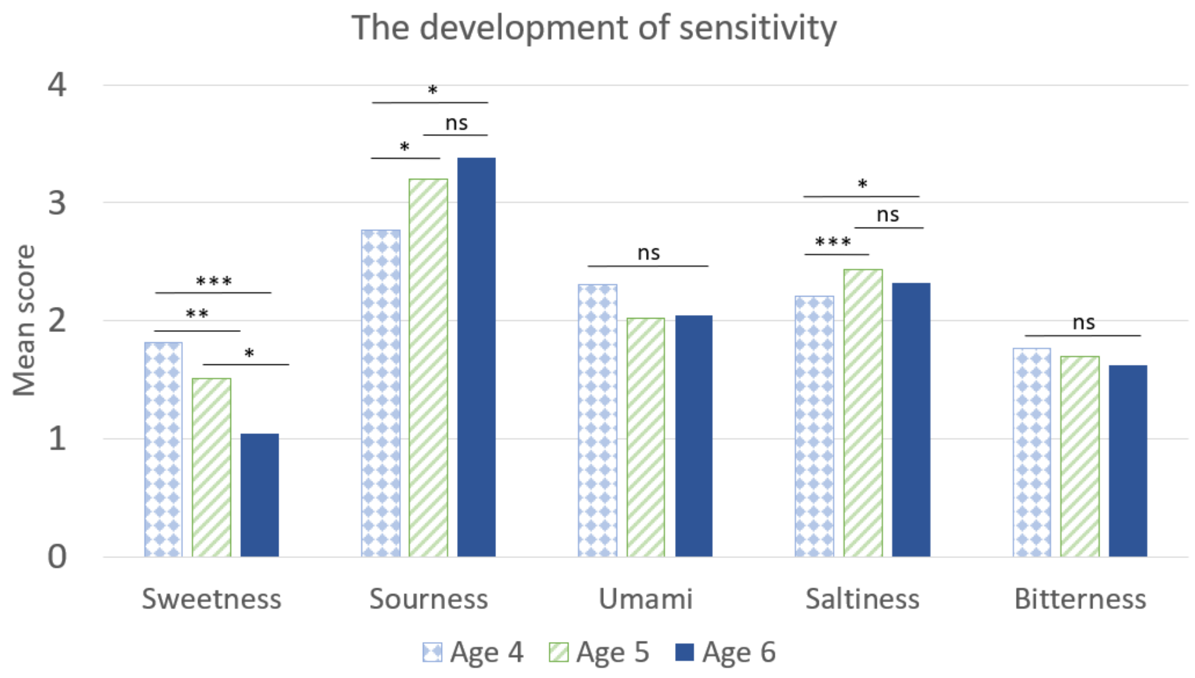

Figure 3: The development of sensitivity for sweet, sour, umami, salt, and bitter stimuli at age four (beams with diamonds), five (striped beams), and six years old (solid beams). Stars indicate significant differences at $p<0.05^{*}$, $p<0.01^{**}$ and $p<0.001^{***}$.

The individual sensitivity development profiles indicate that the children generally had a low sensitivity for sweetness, with 75% of the children either having a stable low or a decrease in sensitivity score (Table 3). For sour taste, the general trend was opposite, with 85% of the children either having a stable high or an increase in sensitivity score. In umami and bitter taste, the majority of the children show stable sensitivity, but with individual differences in group membership. For salty taste, 30% of the children had an increase, and the other children were almost equally divided in the other groups.

Table 3: Percentages of children in each sensitivity development profile

	Stable low [a]	Stable medium [b]	Stable high [c]	Increase [d]	Decrease [e]	Other [f]
Sweet taste	35%	6%	3%	11%	40%	5%
Sour taste	5%	2%	45%	40%	4%	4%
Umami taste	12%	32%	23%	12%	12%	9%
Salty taste	13%	14%	17%	30%	17%	9%
Bitter taste	49%	12%	7%	10%	12%	10%

[a] Lowest or second lowest score for all years, [b] The two middle scores for all years, [c] Highest or second highest score for all years, [d] At least two points higher on score at age six than age four [e] At least two points lower at age six than at age four, [f] all other development patterns

3.4. Relationship between preference and sensitivity scores

For beverages, there was a significant negative association between sweet taste sensitivity and preference at age four, τ_b=-.294, p=.033, age five, τ_b=-.297, p=.031, and age six, τ_b=-.301, p=.029, with children more sensitive to sweetness preferring less sweet drinks. Additionally, there was a significant negative association of small amplitude between bitter sensitivity and sweet taste preference, τ_b=-.163, p=.049, at age six, with children more sensitive to bitterness preferring less sweet drinks. There were no significant relationships between sour or bitter beverages and sensitivity.

There was a significant association of small amplitude between preference for chocolate and sweetness sensitivity at both age four (τ_b=.-208, p=.018) and five (τ_b=-.164, p=.034) and bitterness sensitivity at both age four (τ_b=.-168, p=.025) and five (τ_b=-.164, p=.038), with children more sensitive to both bitterness and sweetness preferring more bitter chocolate.

4. Discussion

Humans are born with innate taste preferences. This paper investigated how taste preferences evolve from the age of four to six, and how they relate to taste sensitivity. Additionally, we investigated how taste sensitivity develops. The different basic tastes did not follow the same general trends, neither for sensitivity nor for preference. Thus, it appears that the development of basic taste preferences does not solely rely on the development of basic taste perception. Even though the global sample of children showed a significant increase or decrease in both sensitivity and preference for several tastes, large individual differences were observed. This suggests that the development of sensitivity and preference does not follow specific child-development stages, but may rely on environmental factors, such as dietary habits and taste exposure.

Preschoolers are not considered the most reliable informers, and previous studies have struggled with collecting sensory data from this age-group (Knof et al., 2011; Liem, Mars, et al., 2004a). Great care was therefore taken in designing tests that the children could perform at the youngest age. Retests revealed that the children were reliable in their answers (Vennerød, Hersleth, et al., 2017). Our procedure was designed to ~~not~~ decrease the influence of differences in ~~rely~~ ~~on~~ cognitive development, and we found different ~~developmental~~ trajectories of perception with age across the basic tastes. We therefore argue that the ~~developmental~~ changes~~trends~~ found ~~are~~ could be due to taste ~~development~~change per se.

Stability in sour taste preference

The preference for sourness was remarkably stable in this study as only 14% of the children had an increase or decrease in taste preference (Table 2). It therefore seems as preference for sourness is formed before the age of four. Even though sour preference was stable with age, there were large differences in preference between the children. In our study, 30.5% of the children had the highest possible sour preference for all three years (Table 2). Similarly to our results, previous studies have found some children to prefer strong sour taste, both at 18 months (Blossfeld et al., 2007), at ages five to nine years (Liem & Mennella, 2003), and at ages six to eleven years (Liem & De Graaf, 2004).

The preference for sourness was not related to taste sensitivity, which did increase over the three testing years for 40% of the children (Table 3). It therefore seems that preference for sour taste is not influenced by taste perception for sour stimuli, which is in line with previous studies (Liem & Mennella, 2003; Liem, Westerbeek, et al., 2004). In addition, unlike preference for sweetness, Liem and de Graaf (2004) found sourness preference to be unaltered by repeated exposure to sour foods in children aged six to eleven years old. Liem, Westerbeek and colleagues (2004) therefore propose that sourness preferences are mediated by intrinsic factors in the child other than sensitivity. Our data support that there is a heightened sourness preference in some children, and that this preference is not due to differences in sensitivity.

Increase in preference for sweet taste

The major proportion of the children either had a stable sweet preference (39.8%, Table 2) or ended up with a high sweet preference for drinks. Unlike for sour taste, there was a significant increase in sweet taste preference, in both sweet drinks (20.3%) and the more complex taste carrier chocolate (25% decrease in bitterness preference, corresponds to an increase in preference for sweetness). The increase in sweet taste preference with age fits with the results of Lanfer and colleagues (2013), who found sweet preferences to increase between the ages of six to nine in a cross-sectional study. However, unlike studies that found an increase in sensitivity for sucrose both with the same age-group as ours (Visser et al., 2000) and children between the age of seven and 14 (Joseph et al., 2016), we found a decrease in sensitivity to sweet taste (40% of the children, Table 3). Both previous studies were however cross-sectional, and in the preschool study the authors argue that the effect was small, with few children in each age-group, and could be due to lack of ability to concentrate in the youngest children (Visser et al., 2000). In our study, some of the increase in preference could be explained by the decrease in sensitivity, but although significant, the correlation was of small amplitude. Thus, sensitivity for sweetness can only partly explain increase in preference for higher sweetness levels, while other factors further contribute.

An important possible factor for the increase in sweet preference could be exposure to sweet foods. Sweet preferences have been found to be influenced by experiences as early as the age of six months (Beauchamp & Moran, 1984) and to be influenced by repeated exposure in six to eleven year olds (Liem & De Graaf, 2004). However, it has also been found to be weakly or not at all related to sweet consumption in children aged seven to twelve (Divert et al., 2017). In a previous paper only investigating the first two years of data of the present study, we found the children's sweet taste preferences to be influenced by at-home exposure to sweet foods (Vennerød et al., 2017). It therefore seems likely that exposure to sweet foods could continue influencing sweet preferences until the age of six. Altogether, this corroborates on the existing knowledge that sweet preferences are impressionable within the childhood years.

~~Continual~~ Stable preference in bitterness

In bitter drinks, 76.1% (Table 2) of the children were stable in their preferences over the preschool years. We did not find developmental differences in sensitivity for bitter, as it was stable for 68% of the children (Table 3). The influence of bitter sensitivity on preference for bitter chocolate was significant, but small, with children more sensitive to bitterness preferring the chocolates higher in cocoa, which were more bitter and less sweet. As there is an interesting relationship between bitterness and sweetness, and there is no association between bitter drinks and sensitivity, this is discussed separately below.

The established effect of our biology on rejection of bitter taste (Mennella, Spector, Reed, & Coldwell, 2013) indicates a general low acceptance for bitterness in the preschool years, but indifference has been observed with infants (Schwartz et al., 2017). In the present study, 19.7% of the children had a stable high bitter taste preference in drink throughout the study (see Table 2). In a previous paper from the same longitudinal study, we reported a relationship between a high exposure to bitter snacks (among other dark chocolate) and a higher preference for bitterness in chocolate (Vennerød, Almli, et al., 2017). We therefore propose that a minority of the children in this study had a high preference for bitter stimuli, and this is not due to a low sensitivity, but rather an actual preference for higher bitterness due to higher familiarity to bitter taste, in relation to dietary exposure. Sensitivity itself could however also be influenced by dietary exposure.

Across taste modalities: Bitterness and sweetness interactions

There was an interesting relationship across taste modalities, with children more sensitive to either bitterness or sweetness preferring chocolates with higher levels of cocoa (i.e. more bitter and less sweet). Additionally, the more bitter sensitive children preferred less sweet drinks. This does not corroborate previous studies that found a positive correlation between quinine sensitivity and sucrose preference in adults (Duffy et al., 2003; Hayes & Duffy, 2008), nor those regarding the genetic influence on sweetness (Joseph et al., 2016; Mennella, Pepino, & Reed, 2005). In addition to the effects discussed above, genotypes of TAS2R38 have been found to influence both PROP (a bitter taste carrier) sensitivity and preference for sweetness (Mennella et al., 2005), and sucrose threshold and sugar intake (Joseph et al., 2016): children more sensitive to bitterness have a higher sensitivity, intake, and preference for sweetness. One reason for our opposite trends could be development across the life span, as the studies mentioned involve adults (Duffy et al., 2003; Hayes & Duffy, 2008), or older children with a mean age of eight (Mennella et al., 2005) or ten years (Joseph et al., 2016). As we see development both in preference and in sensitivity for sweetness, our results could therefore have been different if we tested the children at a later age. Additionally, note that different bitter compounds were used across these studies, as well as within our study since bitterness sensitivity was tested with quinine, which was neither present in our bitter beverage samples nor in our chocolate samples.

Saltiness and umami sensitivity

We found an increase for sensitivity to saltiness. This is particularly interesting as several cross-sectional studies with older children have not found a developmental trend (Bobowski & Mennella, 2015; Lanfer et al., 2013). Too much salt in a diet is not recommended, and previous studies have found a link between sensitivity to saltiness and blood pressure in children (Arguelles et al., 2007; Bobowski & Mennella, 2015), though the relationship is not fully understood (Bobowski & Mennella, 2015). Additionally, children have a preference for salty taste, and salt preference in children is related to real-life food intake (Bouhlal, Chabanet, Issanchou, & Nicklaus, 2013). A better understanding of the development of salty taste perception can thus have important consequences for the prevention of health conditions.

The stability in sensitivity to umami taste fits with previous cross-sectional results on children between the ages of six and nine (Lanfer et al., 2013). An increase in sensitivity for umami has been found between six-year olds and 18-year olds (Overberg, Hummel, Krude, & Wiegand, 2012), but in this study the test relied on taste recall, and participants often confused umami with salty taste. Umami taste can be particularly challenging to study, as it is a complex lingual category for Norwegian children, but this study demonstrates that by focusing on taste detection and not identification, it can be investigated with young children.

Methodological considerations

To our knowledge, this is the first study to investigate taste sensitivity and preference with preschoolers using a longitudinal design. We argue that this is an important methodological strength of the present study. Careful considerations were taken in designing protocols for sensitivity and preference tests that were tailored for preschoolers, which we propose to be the other main strength of the study. The study does however present several limitations.

When doing sensory tests, the choice of taste carriers will influence the results. In this study, it was important to have child-friendly stimuli that could be easily produced identically during all years of the study. This constraint affected in particular our choice of bitter stimuli. As children generally will reject a strong bitter taste, we chose not to make the bitter samples *too* bitter. To reveal larger differences in bitter taste preference between the children, the bitter drinks could have contained even more isolone, and the most bitter chocolate could have contained more than 65% cocoa. The bitter drinks and the chocolate samples provided in this study all contained sugar, which can mask the adverse effect of bitter stimuli (Mennella et al., 2014). As such, the bitterness might not have been unpleasant enough to better detect variation across children and over years. The results might therefore not be generalizable for bitterness preference in other taste carriers. The same may be true for the sweet and sour drinks as well. However, the strongest sweet drink contained 18% sugar, whereas, as an example, Coca-Cola® contains 10.6% sugar (Coca-Cola, 2018). Our strongest sweet beverage could therefore be described to be extremely sweet.

In addition, one may argue that using other basic taste concentrations in the sensitivity task may have led to different results. This would particularly be interesting for sourness, as the children generally had a very high sourness sensitivity based on our stimuli. Perhaps higher dilutions could have revealed a different relationship. However, there was an increase in sensitivity for sourness, and comparable studies did not find a relationship between sensitivity and preference for sourness (Liem & Mennella, 2003; Liem, Westerbeek, et al., 2004). Further, for bitterness the results could have been different with other compounds. It has been suggested that more than 500 bitter compounds exists (Wiener, Shudler, Levit, & Niv, 2011), and we used quinine (sensitivity), isolone (drinks), and theobromine from cocoa (chocolates). Quinine was chosen as it is authorised in testing with children, unlike PROP and caffeine. Our results are therefore partly related to this choice.

5. Conclusion

This study aimed at understanding how taste preference and sensitivity develop in the preschool years between the ages of four and six, and how the two relate to each other. We found stability in taste preferences for both sourness and bitterness, and a developmental increase in preference for sweetness, corroborating previous cross-sectional studies. There was no global developmental trajectory for sensitivity, with an increase in sensitivity for sourness and saltiness, decrease for sweetness, and stability in umami and bitterness. The weak relationship between taste sensitivity and taste preference in our data suggests that taste preference development is shaped by a multitude of factors in addition to taste sensitivity. The individual differences in development of both sensitivity and preferences propose that no general developmental stage exists, but that sensitivity and preference are shaped by environmental factors. We suggest that future research should follow children for an even longer period, to investigate at what time sour preferences are formed, and if dietary intake can serve as a mediator in the preference-sensitivity relationship.

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