Norwegian University of Life Sciences
Faculty of Chemistry, Biotechnology and Food Science
Department of Life and Food Science

Philosophiae Doctor (PhD)
Thesis 2021:83

Taste sensitivity and food liking in preadolescent children

Smakssensitivitet og matpreferanser hos barn

Ervina

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‘… all deeds come to an end, except three:
recurring charity, **knowledge (by which people) benefit**,
and a righteous child who prays (for the deceased) ...’
The Book of Hadith, Sahih Muslim: 1631

I hope this doctoral thesis can provide a small contribution
for those who need a reference in the field of sensory sensitivity in children

Contents

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Ervina

List of Papers

Paper 1

Ervina, E., Berget, I., Nilsen, A., & Almli, V. L. (2020). The ability of 10–11-year-old children to identify basic tastes and their liking towards unfamiliar foods. *Food Quality and Preference, 83*, 103929. https://doi.org/10.1016/j.foodqual.2020.103929

Paper 2

Ervina, E., Berget, I., & Almli, V. L. (2020). Investigating the Relationships between Basic Tastes Sensitivities, Fattiness Sensitivity, and Food Liking in 11-Year-Old Children. *Foods, 9*(9). https://doi.org/10.3390/foods9091315

Paper 3

Ervina, E., Berget, I., Borghild, S.S., & Almli, V. L. (2021). Basic taste sensitivity, eating behaviour, and propensity of dairy foods of preadolescent children: How are they related?. *Open research Europe*. Submitted

Paper 4

Ervina, E., Almli, V. L., Berget, I., Spinelli, S., Sick, J., Dinnella, C. (2021). Does Responsiveness to Basic Tastes Influence Preadolescents' Food Liking? Investigating Taste Responsiveness Segment on Bitter-Sour-Sweet and Salty-Umami Model Food Samples. *Nutrients, 13*(8), 2721. https://doi.org/10.3390/nu13082721

Abbreviations

AFC	Alternative Forced Choice
ANOVA	Analysis of Variance
BMI	Body Mass Index
CA	Correspondence Analysis
CEBQ	Child Eating Behaviour Questionnaire
DCES	Daily Consumption Equivalence Scores
FFA	Free Fatty Acid
FPQ	Food Propensity Questionnaire
GDPR	General Data Protection Regulation
gLMS	Generalized Labelled Magnitude Scale
GPCR	G-Protein Coupled Receptor
ICFSN	Italian Child Food Neophobia Scale
ISO	International Standard Organization
LAM	Labelled Affective Magnitude
LMS	Labelled Magnitude Scale
MFA	Multiple Factor Analysis
mGluR	Metabotropic Glutamate Receptor
MSG	Monosodium Glutamate
NaCl	Sodium Chloride
PCA	Principal Component Analysis
PKD	Polycystic Kidney Disease channel
PROP	6-n-propylthiouracil
TAG	Triacylglyceride
TRC	Taste Receptor Cell
WHO	World Health Organization

Summary

Taste is a key factor in determining food palatability and affects food acceptance. Children have been reported to have different taste sensitivity perceptions, which may influence their food preferences. The main objective of this study was to investigate the relationship between taste sensitivity and food liking in preadolescent children. Additionally, the associations among children's taste sensitivity, eating behaviour and food propensity were also investigated. The correlations between taste sensitivity measurements were evaluated and two bitter compounds of quinine and caffeine involved. Moreover, the relationships among taste sensitivity, food choice, familiarity and food neophobia were also explored.

Three studies were conducted to answer the main objective. A total of 98, 106 and 148 preadolescent children participated in studies 1, 2 and 3, respectively. Different taste carriers, such as real food samples (studies 1 and 3) or single taste compound in water solutions (study 2), were employed to measure taste sensitivity in children. Taste sensitivity was measured with different approaches: taste modality recognition (study 1), detection and recognition threshold (study 2) and perceived taste intensity (studies 2 and 3). In addition, the children's parents completed a questionnaire regarding their children's eating behaviour and food propensities.

This study highlighted the relationships between individual differences in taste sensitivity and food liking. Children with high sensitivity to bitter and sour tastes and those with low sensitivity to sweet taste had a lower liking of grapefruit juice samples. Additionally, children with generally low sensitivity to basic taste significantly increased their liking in parallel with the increase of sugar addition. These relationships could be modulated by different taste responsiveness of a specific tastant. Moreover, fattiness sensitivity was associated with the liking of fatty foods. These results indicate that individual differences in taste and fattiness sensitivity were able to influence food liking. However, the same pattern was not found in vegetable broth samples, suggesting that the relationships between taste sensitivity and hedonic responses in preadolescents are taste- and product-dependent as well as subject-dependent. Different taste carriers and methods used to evaluate taste sensitivity and hedonic responses may generate different results, suggesting that the selection of the method and type of taste carrier should be considered in future studies. All three studies, however, confirmed higher preferences for sweetness and aversion to bitterness and sourness in preadolescents.

The different measurements of taste sensitivity were correlated. These correlations, however, appear to be weak, indicating that different measurements may capture different aspects of taste perception. Children have a good ability to identify basic taste modalities in unfamiliar foods, and they also demonstrate to have different intensity perceptions and liking of caffeine and quinine. Moreover, children's taste detection threshold was shown to be associated with eating behaviour, and our study showed no

association between taste sensitivity and food propensity. This study confirms a positive association between food approach and children's BMI, while food avoidance showed a negative association. There was no significant influence of taste sensitivity on children's food choice, familiarity or neophobia.

In conclusion, this study demonstrates that preadolescents' food acceptance is significantly influenced by their individual responses to taste intensity perceptions. The results in this thesis can be implemented to develop effective strategies to increase preferences for healthy foods in preadolescents, especially foods that generally have low acceptance, such as bitter vegetables.

Sammendrag

Smakssansen er en av nøkkelfaktorene for hvordan vi oppfatter smak og hvordan dette påvirker vår aksept for mat. Det er rapportert at barn har ulik smaksensitivitet, og dette kan påvirke deres matpreferanser. Hovedmålet med denne studien var å undersøke sammenhengen mellom barns smaksensitivitet og matpreferanser. I tillegg, ble sammenhengen mellom barns smaksensitivitet, spiseatferd og hvilken mat de foretrakk også undersøkt. Videre ble korrelasjonen mellom forskjellige metoder for å måle smakssensitivitet evaluert. To forskjellige forbindelser, kinin og koffein, ble brukt for å måle sensitivitet for bittersmak. Videre, ble forholdet mellom barnas smaksensitivitet, matvalg, kjennskap til ulike matvarer, og mat neofobi også undersøkt.

Tre forskjellige studier ble utført for å besvare hovedmålsetningen. Totalt 98, 106 og 148 barn deltok henholdsvis i studie 1, 2 og 3. Forskjellige smaksprøver, ulike matvarer (studie 1 og 3) eller vannløsninger (studie 2) ble brukt for å måle smaksensitivitet hos barn. Smaksensitivitet ble målt med forskjellige metoder, nemlig ved gjenkjennelse av smakene (studie 1), terskel for deteksjon og gjenkjenning av smakene (studie 2) og smakintensitet (studie 2 og 3). I tillegg har foreldrene også fylt ut et spørreskjema om barnas spiseadferd og hva slags matvarer barna har tilbøyelighet til å velge.

Denne studien påpeker forholdet mellom individuelle forskjeller i smakssensitivitet og matpreferanser. Barn med høy sensitivitet for bitter og sur smak, og de med lav sensitivitet for søt smak hadde lavere preferanse for grapefruktjuiceprøver. I tillegg hadde barn med generelt lav sensitivitet for grunnsmakene signifikant høyere preferanse for økt sukkertilsetning. Preferanse for mat med økt innhold av fett, var knyttet til fettsensitivitet. Disse resultatene indikerer at individuelle forskjeller i smaksensitivitet kan påvirke barnas preferanser. Det samme mønsteret, ble imidlertid ikke funnet for grønnsakbuljong. Dette indikerer at forholdet mellom smaksensitivitet og hva barn liker er avhengig av smak og produkt så vel som barnet. Ulike typer smaksprøver og metoder som brukes til å evaluere smaksensitivitet og preferanser kan gi forskjellige resultater. Valg av metoder og smaksprøver bør derfor vurderes i fremtidige studier. Alle de tre studiene bekreftet at barn har høyere preferanse for søtsmak og aversjon mot bitter og sur smak.

Forskjellige metoder for å måle smaksensitivitet ble sammenlignet. Imidlertid ser korrelasjonene mellom de ulike metodene ut til å være svake, dette indikerer at forskjellige metoder kan måle ulike aspekter av barns smaksoppfatning. Barn har god evne til å identifisere ulike grunnsmaker i ukjente matvarer, de har også forskjellig intensitetsopplevelse for bittersmak i koffein og kinin, og liker disse i ulik grad. Barns terskel for å gjenkjenne smak var assosiert med spiseatferd, men det ble ikke funnet noen sammenheng mellom smaksensitivitet og hva slags mat de foretrakk. Studien bekrefter at barn med høy BMI viser større interessere og tiltrekning mot mat, mens

barn med normal BMI i større grad avviser mat. Det var ingen signifikant påvirkning av barnets smaksensitivitet på matvalg, matkjennskap eller matneofobi.

Denne studien viser at barns matpreferanser er påvirket av deres individuelle oppfattelse av smakintensitet. Dette kan bli brukt til å utvikle mer effektive strategier for å fremme sunt kosthold hos barn og unge, spesielt for matvarer som har lav preferanse hos barn, for eksempel bitre grønnsaker.

1. Introduction

1.1. General Introduction

The worldwide prevalence of overweight and obesity in children is increasing significantly, from 4% in 1975 to nearly 20% in 2016, resulting in 340 million children and adolescents aged 5–19 who are overweight or obese (WHO, 2017). These numbers have increased sharply in recent decades, making childhood obesity a global pandemic issue (WHO, 2017). Recent data from the World Health Organization (WHO) in Europe show that the prevalence of overweight and obesity is nearly 30% in children aged 6–9 years (Kiaer & Olsen, 2021). Overweight and obesity in children have become a global concern because of their long-term health consequences. Children with obesity are very likely to remain obese when they become adults, and they have an increased risk of developing non-communicable and metabolic diseases that will significantly affect their morbidity and mortality (Sahoo et al., 2015). The fundamental cause of overweight or obesity is an imbalance between energy intake and expenditure, mainly due to increasing consumption of energy-dense foods characterised by high sugar and fat in addition to limited physical activities (Sahoo et al., 2015; WHO, 2017). However, the aetiology of obesity in children is far more complex than just an imbalance of energy intake and expenditure, obesity is multifaceted and involving factors not only at the individual level but also at the community and governmental levels that promote obesogenic environments (Lytle, 2009).

The association between overweight or obesity and taste preference is well established (Cox, Hendrie, & Carty, 2016; Donaldson, Bennett, Baic, & Melichar, 2009) since taste is one of the important sensory cues that builds sensory profiles, contributes to food palatability and initiates food intake (Boesveldt & de Graaf, 2017; McCrickerd & Forde, 2016). Taste could directly influence liking and become a key factor in children's food choices and preferences (Blissett & Fogel, 2013; Boesveldt et al., 2018; Nguyen, Girgis, & Robinson, 2015; Oellingrath, Hersleth, & Svendsen, 2013). The development of taste preferences has already started in newborns (Steiner, Dieter, Maria, & Kent, 2001), while exposure to taste stimuli begins during the gestational period via amniotic fluid from the mother (Mistretta & Bradley, 1975; Nicklaus, 2016). Food preferences are associated with food intake in children: for example, intake of fruits and vegetables in 10–12-year-old was strongly correlated with their preferences for these food categories (Bere & Klepp, 2004). However, vegetable and fruit intake in preadolescent children did not meet the recommended daily intake (Hansen, Myhre, Johansen, Paulsen, & Andersen, 2016; Sandvik et al., 2005); children also prefer sugary and fatty foods (Ahrens, 2015; Ervina, Berget, & Almli, 2020), which will lead to over-caloric consumption and increase their risk of overweight and obesity (Intemann et al., 2017; Leonie et al., 2018).

Children's food preferences and likings have been reported to be associated with their taste sensitivity (Hartvig, Hausner, Wendin, & Bredie, 2014; Vennerød, Nicklaus, Lien, & Almli, 2018). Moreover, children have different responses towards different intensities of taste stimuli (Ahrens, 2015; Joseph, Reed, & Mennella, 2016). This led to the main research question of this study: to investigate whether individual differences in taste sensitivity will result in different food liking patterns in preadolescent children. Taste sensitivity is an individual ability to respond to taste stimuli (Webb, Bolhuis, Cicerale, Hayes, & Keast, 2015). It has been reported that taste sensitivity is associated with food preferences, BMI and lifestyle in children aged 8–9 years (Rodrigues et al., 2020). Moreover, sensitivity to bitterness in 9–11-year-old children significantly influenced their intake of bitter juices such as grapefruit and aronia (chokeberry) juices (Hartvig et al., 2014), indicating that children with high sensitivity to bitter taste have a lower intake of bitter juices compared to low-sensitivity children. This suggests that different taste sensitivities in children may influence their food acceptance.

This thesis measured and reported children's basic taste sensitivities of sweetness, sourness, saltiness, bitterness and umami. In addition, fattiness was also investigated, and two bitter compounds of caffeine and quinine were involved. According to our current knowledge, studies regarding the relationships between preadolescents' taste sensitivities and food liking by involving all basic taste modalities are still limited. The latest population-based study of taste sensitivities involved more than 1,800 children aged 6–9 years involving four taste modalities and it excluded sourness sensitivity (Ahrens, 2015). Most other studies have focused only on sensitivity to bitter and/or sweet tastes (Joseph et al., 2016; Lim et al., 2021; Mennella & Bobowski, 2015; Rodrigues et al., 2020; Vennerød et al., 2018). Umami taste has also gained more attention in recent years and should be evaluated in taste-sensitivity studies since this taste is highly associated with food palatability and preferences (Kurihara, 2015). The unfamiliarity of the umami taste in children, however, hindered its involvement in previous studies (Cecchini et al., 2019; Mustonen, Rantanen, & Tuorila, 2009).

This thesis also addresses the relationships among children's taste sensitivity, eating behaviour and food propensity. In addition, the associations among taste sensitivity, food choice, food familiarity and neophobia were also explored. A previous study suggested that 5–10-year-old children who were sensitive towards basic taste stimuli were more susceptible to becoming selective eaters compared to less sensitive children (Farrow & Coulthard, 2012). Moreover, sensitivity to sweetness in 8–9-year-old children was associated with their lifestyle (Rodrigues et al., 2020). The relationships among children's taste sensitivity, eating behaviour and health have been investigated at the molecular and genetic levels (Chamoun et al., 2018; Hughes & Frazier-Wood, 2016). The latest large-scale genetic studies have provided convincing evidence for particular genes and pathways involved in eating regulations that could directly influence BMI and eating behaviour (Locke et al., 2015). Children's eating frequency of certain foods has also been reported to be associated with their taste sensitivity. Children with low sensitivity to sweet taste have higher-frequency consumption of sweet foods, while children with low sensitivity to bitter taste were reported to have higher exposure to bitter foods (Vennerød, Almli, Berget, & Lien, 2017).

Preadolescence is a critical period for the development of lifelong eating habits, and, at the same time, children in this age group have the potential to become selective eaters (Gibson et al., 2012; Viljakainen, Figueiredo, Rounge, & Weiderpass, 2019). It is important to build healthy food habits during childhood because the healthy eating habits that develop at this time will remain through adulthood (Nicklaus & Remy, 2013). Understanding the relationship between taste sensitivity and food liking will contribute to developing a comprehensive and effective strategy to promote healthy eating in preadolescent children by considering their taste sensitivity since our study confirms the influence of individual differences in taste sensitivity on children's food liking.

In this thesis, the literature foundation and background regarding basic taste perceptions are presented in chapter 1, with some of the references presented in this chapter used to explain the findings in the discussion. This will be followed by the main research objective and methodology, which are described in chapters 2 and 3, respectively. A summary of each paper and the overview findings of the studies are presented in chapter 4, while chapter 5 provides a discussion based on the results and findings obtained. A conclusion and future perspective are presented at the end of this thesis; they aim to reflect the findings, contribute to healthy eating strategies in preadolescents and suggest some important considerations for future studies.

1.2. Taste perception and the basic taste modalities

Taste is defined as a sensory modality perceived by the gustation system from chemical compounds that can stimulate taste receptors (Breslin, 2013). To be acknowledged as a taste, two important requirements must be met: first, taste must have a specific taste receptor, and second, it should have a clear mechanism of perception from the receptors to the brain. According to Breslin (2013) there are five different aspects of taste perception: 1) taste modality recognition, 2) taste intensity perception, 3) temporal dynamic of taste, 4) spatial location of taste and 5) hedonic response to taste. For example, when subjects drink grapefruit juice, they could perceive all different aspects of taste perceptions in their gustatory system, such as: 1) recognising the bitter and sour tastes of grapefruit juice (modality recognition), 2) perceiving the strong or weak intensity of the bitter and sour tastes (intensity perception), 3) perceiving the bitter taste longer than the sour taste (temporal dynamic perception), 4) perceiving more bitter taste on the back of the tongue (spatial location) and 5) liking or disliking the taste of grapefruit juice (hedonic). In this thesis, the focus will be narrow: on taste modality recognition, intensity perception and hedonic responses.

There are five taste modalities, also known as 'basic tastes', that can be perceived by the human gustatory system: sweet, salty, sour, bitter and umami. In addition, the taste of fat or 'fattiness' has been considered as the sixth basic taste modality (Besnard, Passilly-Degrace, & Khan, 2016; Russell & Andrew, 2015), although the inclusion of fattiness as a basic taste is still debated (Heinze, Preissl, Fritsche, & Frank, 2015; Russell & Andrew, 2015), despite the potential receptors and mechanisms of fattiness perception having been well-established (Chamoun et al., 2018; Russell & Andrew, 2015).

1.2.1. Sweet taste

Sweet taste is known as the taste of 'pleasure' (Mennella & Bobowski, 2015) since this taste is strongly associated with food acceptance, particularly for children (Mennella, Finkbeiner, Lipchock, Hwang, & Reed, 2014; Schwartz et al., 2017; Vennerød et al., 2018). This taste is biologically preferred among other tastes since sweet signals human nutrients, such as sugar from carbohydrates (Reed & Knaapila, 2010), which are critical to the human body to generate energy. Neonates showed a preference for sweet taste, as demonstrated by their affective behaviour, such as smiling, wanting and sucking investigated using the facial-expression method (Steiner et al., 2001). This shows that the preference for sweet taste is already developed in neonates.

Children prefer a higher level of sweet intensity compared to adults (Mennella & Bobowski, 2015; Zandstra & de Graaf, 1998). A study by Mennella, Lukasewycz, Griffith, and Beauchamp (2011) involving 356 children (5–10 years) and 169 adolescents (10–19 years) revealed that both groups preferred sucrose solutions at 0.60 M (equivalent to 21 g sucrose/100ml of water), while the adult group preferred a concentration of less than half of this, around 0.34 M (equivalent to 12.2 g/100 ml of water). This evidence shows that children and adolescents may be more prone to consume sugar-sweetened foods because they prefer high intensity of sucrose. Sweet taste can generate pleasure in eating, but the perception of sweetness intensity and liking of highly concentrated sweetness solutions differed among subjects (Reed, Tanaka, & McDaniel, 2006). According to Iatridi, Hayes, and Yeomans (2019), subjects can be categorised as 'sweet likers': this group had a higher liking when the sweetness intensity increased, and no concentration of sweetness was considered as too much for this group. Another group is called 'sweet dislikers': they did not like when the sweet intensity was too much and decreased their liking as the sweetness intensity increased. The last group is called the 'inversed U-shape' group: this group increased their hedonic response in accordance with the increase of sweet intensity until a certain concentration level, then their hedonic response dropped when the sweetness intensity became too much for them.

1.2.2. Bitter taste

Bitter taste is often considered as the opposite of sweet taste: instead of generating wanting and liking, this taste is strongly associated with food rejection (Mennella & Bobowski, 2015). Humans naturally reject bitter foods because this taste is associated with poisonous substances, even though not all bitter taste is toxic: for example, vegetables dominantly taste bitter but are rich in micronutrients, such as vitamins and minerals, which provide health benefits. Bitterness was reported to have the largest number of taste compounds compared to the other four basic tastes, with more than 10,000 different molecules responsible for this taste (Briand & Salles, 2016). Moreover, around 25 different taste receptors have been investigated and related to bitter taste perception in humans (Behrens & Meyerhof, 2013; Meyerhof et al., 2010), which shows the complexity of bitterness perception.

In one study, neonate subjects showed a strong rejection for bitterness since they gaped, wrinkled their noses, shook their heads and frowned when a bitter substance was placed in their mouths (Steiner et al., 2001). Children aged 3–10 years were reported to have a higher bitter sensitivity compared to adults (Mennella, Pepino, Duke, & Reed, 2010), indicating that they perceived bitter taste as more intense than did the adults. This could escalate the rejection of bitter foods, such as vegetables in children. Bitter sensitivity is an important factor in the acceptance and intake of fruits and vegetables in children (Bell & Tepper, 2006; Goldstein, Daun, & Tepper, 2007; Keller & Adise, 2016). Children also have a higher percentage of supertasters than do adults, according to their PROP (6-n-propylthiouracil) phenotyping, with more than 30% of children reported as supertasters (Borazon, Villarino, Magbuhat, & Sabandal, 2012; Ervina, Berget, & Almli, 2020). This number is higher than the general supertaster group found in the normal adult population, which is around 25% (Keller & Adise, 2016), indicating that children are more sensitive to bitter taste than adults.

1.2.3. Sour taste

Similar to bitter taste, sour taste also triggers avoidance since this taste is associated with spoiled or fermented foods (Reed & Knaapila, 2010). Some studies, however, reported that sour taste can initiate liking (Ervina, Berget, & Almli, 2020; Liem, Westerbeek, Wolterink, Kok, & de Graaf, 2004), suggesting that a preference for sour taste in children provided equivocal results. Children aged 7–12 years who had a heightened preference for sour taste had a higher willingness to try new foods and also showed a higher preference for more intense taste stimuli (Djien Gie Liem et al., 2004). In addition, 11-year-old children showed to like sour taste from citric acid in the aqueous solution sample at the concentration level of 0.02 g/100 ml of water (Ervina, Berget, & Almli, 2020). By contrast, children aged 9–14 years preferred to consume fruit drinks with low sourness intensity, indicating a negative association between sourness and children's food liking (Kildegaard, Tønning, & Thybo, 2011). The acceptance of sour taste depends on the context and concentration level of this taste in foods. For example, sourness in lemonade at a low concentration is desirable, and people expect a sour tartness from cultured milk but not in pasteurised milk (Reed & Knaapila, 2010).

1.2.4. Salty taste

Salt (sodium chloride, NaCl) is a very common ingredient added to foods to enhance flavours and act as a preservative in processed foods (Liem, 2017). This compound is also essential in regulating the osmotic pressure and extracellular fluid movement in the human body (Liem, 2017; Reed & Knaapila, 2010). Our bodies will get dehydrated if we lack salt, but too much salt is not recommended because it could increase the risk of hypertension and cardiovascular diseases (Ha, 2014). Therefore, salt reduction in processed foods has become one of several public health strategies to reduce overall salt intake. Perceived saltiness intensity was reported to be correlated with liking and significantly influence food intake (Lucas, Riddell, Liem, Whitelock, & Keast, 2011).

Saltiness sensitivity was reported to be significantly influenced by environmental factors and food exposures rather than by genetic determinants (Reed & Knaapila, 2010). Children's sodium intake increased from 6–13 years and the intake gets even higher when they 14–18 years (Liem, 2017), indicating that saltiness sensitivity might differ across age groups. A study by Kim and Lee (2009) reported that children aged 12–13 years with low saltiness sensitivity (as measured by detection threshold) had a higher preference for stew and soup. There was, however, still insufficient evidence to link children's liking to salty taste towards sensitivity to saltiness and salty food consumption (Liem, 2017). Saltiness level indeed plays an important role in children's liking of various foods, which suggests the importance of studying the relationships between saltiness sensitivity and children's preferences towards salty foods.

1.2.5. Umami taste

Umami is the most recent basic taste to have been acknowledged. Scientists have discovered the receptors for umami taste and revealed the fundamental mechanisms of umami perception (Kurihara, 2015), providing a strong argument for fully accepting umami as one of the basic taste modalities. The taste compound was originally extracted from seaweed and identified as glutamic acid or monosodium glutamate (MSG) (Bellisle, 1999). The umami compound is found naturally in foods like cheese, meat, vegetables and seafood. *Umami* means 'delicious', and this term perfectly describes the use of MSG as a flavour enhancer to improve food palatability. *Umami* is also commonly translated as 'savoury' or 'meaty' (Reed & Knaapila, 2010). Neither the term *umami* nor its taste is as familiar compared to the other four basic tastes particularly in western countries (Cecchini et al., 2019). The inclusion of umami taste in taste sensitivity studies should be combined with a training session to familiarise the participants with this taste modality before the evaluation (Mustonen et al., 2009).

Umami taste could become one of the strategies for reducing salt content in foods without compromising saltiness intensity and maintaining an acceptance level (Hayabuchi et al., 2020). Newborns and infants demonstrate affecting expression when they taste broth added with MSG (Forestell & Mennella, 2017). The higher preferences for umami taste in infants could be due to glutamate content, which is naturally available in breast milk (Koletzko, 2018), because this amino acid (glutamate) plays important roles in maintaining growth and health and protecting neonates against infections and allergies (van Sadelhoff, Wiertsema, Garssen, & Hogenkamp, 2020). Moreover, children aged 6–9 years prefer crackers with the addition of MSG compared to crackers without MSG (Ahrens, 2015), indicating a higher preference for umami taste in children. However, unlike umami taste in the food matrix, the umami taste in a water solution is unpalatable (Beauchamp, 2009) and generates a rejection in children aged 11-year-old when they taste umami in a water solution sample (Ervina, Berget, & Almli, 2020).

1.2.6. Fatty taste

In addition to the five basic tastes, the taste of fat is considered as the sixth taste modality (Besnard et al., 2016). A review by Mattes (2011) suggested that fatty acid acts as a potential taste compound of fattiness. Moreover, two receptors for fatty acids have been discovered, but the underlying mechanism of fatty acid perceptions needs further and comprehensive investigation since fattiness involves not only taste but also other sensory perceptions, such as mouthfeel or texture and odour (Heinze et al., 2015). The perception of fat is characterised by the integration of taste, smell and texture stimuli since fatty acids can stimulate trigeminal neurons, which are responsible for oral texture perception (Yu, Shah, Hansen, Park-York, & Gilbertson, 2012). However, people differed on how much fat is just right for them and which level of fat would be preferred (Reed, 2009). This implies different fattiness perceptions, which may affect food liking.

According to Russell and Andrew (2015), fatty acids might be detected at very low concentration, and the recognition of their presence as a taste at suprathreshold levels might create an unpleasant flavour (e.g., as a result of fat hydrolysis in foods due to rancidity). Therefore, fattiness sensitivity is commonly measured using a detection threshold method (Haryono, Sprajcer, & Keast, 2014). Most fatty acids do not dissolve in water; thus, different emulsions of the food matrix or model foods, such as milk, custard, pudding, cheese or creamy soups, have been used as food samples to measure fattiness sensitivity (Alexy et al., 2011; Ervina, Berget, & Almli, 2020; Haryono et al., 2014; Mennella, Finkbeiner, & Reed, 2012; Stewart, Newman, & Keast, 2011). However, there is no standard method has been determined for either the type of fatty acid or the carrier that should be used in measuring fattiness sensitivity.

Fat can dissolve hydrophobic volatile flavour molecules that are usually not mixed in water. In addition, fat contributes to providing a rich and creamy texture (Drewnowski, 1997), which makes fatty foods taste ‘rich’. These might be one of the reasons that many people prefer fatty foods. Moreover, fat is also associated with sweet and salty tastes in regard to high-density foods (Deglaire et al., 2012; Liem & Russell, 2019), such as salty–fatty foods (pizza, hamburger, fries, chips) or sweet–fatty foods (brownies, ice cream, cakes), and these foods were reported as the most preferred by children (Ahrens, 2015; Ervina, Berget, & Almli, 2020). This shows a positive association between fattiness and children's food liking.

1.3. Anatomy and physiology of taste perception: The basic taste receptors

The different taste compounds (also known as tastants) are perceived by taste buds located in the oral cavity, mainly on the tongue (Briand & Salles, 2016). Taste buds are the onion-like shaped structure that contain different types of taste receptor cells (TRCs), whose plasma membranes contain specific taste detectors that are able to perceive taste compound molecules (Briand & Salles, 2016). TRCs are categorised into three major classes: type I, II and III cells. Type I and III receptor cells are involved in salty and sour taste detection, respectively, while type II cells detect umami, sweet and bitter compounds (Briand & Salles, 2016).

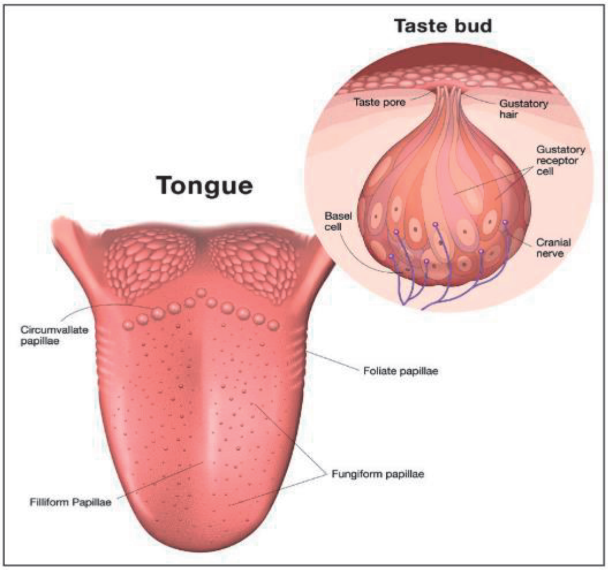

Figure 1. Human tongue anatomy presenting papillae and taste buds. Figure taken from Gravina, Yep, and Khan (2013). This picture is published for educational purposes only with copyright under the Annals of Saudi Medicine (DOI: 10.5144/0256-4947.2013.217)

The taste buds are observed in four major types of papillae spread all over the tongue, which are categorised based on their anatomic structure (Figure 1). The largest papillae are called circumvallate papillae, the round mushroom-like shaped papillae are called fungiform papillae and the leaf-like shaped papillae are called foliate papillae. All these papillae contain taste buds, while another type of papilla, filiform papillae, transduce touch, temperature and nociception but contain no taste receptors (Gravina et al., 2013).

The chemical taste compounds are perceived by taste receptors inside the taste buds. After this process, the taste compound is transduced to the central nervous systems. The taste receptor cells can depolarise and release neurotransmitters, which play a role in signalling and communicating information regarding the taste modalities to the central nervous system (Breslin, 2013). Sweet, bitter and umami tastes are mainly transduced by G-protein-coupled receptors (GPCRs), while sour and salty tastes are mainly transduced by ion channels (Briand & Salles, 2016; Gravina et al., 2013).

Sweet taste is modulated by a single heterodimeric GPCR T1R2/T1R3. These receptors responded to mono- and disaccharides and other sweet compounds (Munger & Meyerhof, 2015). The molecular detection of salty and sour tastes is less known compared to sweet and bitter tastes, but studies have reported that the salty taste receptor is associated with the epithelial sodium channel (ENaC), while sour taste stimuli are transduced via an acid-sensing ion channel (ASIC) and possibly via proton detectors (Breslin, 2013; Gravina et al., 2013). Another receptor for salty and sour has been identified via the polycystic kidney disease (PKD) channels, PKD1L2 and PKD3L1. These two channels have been shown to be involved in sour taste detection (Gravina et al., 2013; Huang et al., 2006). The main compound of umami taste, which is glutamate, is bound to the T1R1/T1R3 receptor (Munger & Meyerhof, 2015) and possibly via the metabotropic glutamate receptor 1 (mGluR1) and metabotropic glutamate receptor 4 (mGluR4) channels (Breslin, 2013).

Compared to the other basic tastes, bitter taste has the most diverse receptors. About 25 different receptors (T2Rs) have been identified as being responsible for bitter taste perception, and among these numbers, the most studied bitter receptor is a polymorphism of TAS2R38, which has been intensively investigated and shown to be associated with PROP responsiveness (Bufe et al., 2005; Meyerhof et al., 2010). Interestingly, bitter and sweet compounds are bound to similar types of GPCRs (Mennella & Bobowski, 2015), suggesting a strong association between bitter and sweet taste perception in humans. The structure of bitter molecule compounds is very diverse; in addition, they also belong to different chemical classes, such as flavonoids, acids, salts, alkaloids, amino acids and peptides (Briand & Salles, 2016) which increase the variety of bitter tastes.

The fatty acid receptor has been reported to be associated with CD36, which can detect both saturated and unsaturated fatty acids (Heinze et al., 2015). The fattiness mechanism from transduction to perception has been previously reported comprehensively by Besnard et al. (2016). Lipids, however, are perceived not only via the gustation pathway but also the trigeminal pathway for texture and mouthfeel sensations.

1.4. Taste sensitivity

Taste sensitivity is defined as an individual's ability to respond to taste stimuli (Winnie, 2008). People react differently on how they perceived the same taste stimuli (Mennella & Bobowski, 2015; Reed & Knaapila, 2010). The field devoted to studying taste sensitivity measurement is known as *psychophysics* (Reed & Knaapila, 2010). This field endeavours to understand the physical stimuli from taste compounds (tastants) and the psychological responses they elicit (tastes). Taste sensitivity can be determined using common psychophysical testing, such as detection threshold, recognition threshold, perceived taste intensity or taste responsiveness, taste modality recognition and fungiform papillae count (Reed & Knaapila, 2010; Webb et al., 2015). In addition, responsiveness to PROP has been used as a general marker for chemosensory perception (Keller & Adise, 2016) because some studies have demonstrated a positive relationship between responsiveness to PROP and taste intensity perception in general, and in particular for bitter taste (Chamoun et al., 2019; Dinnella et al., 2018; Fischer et al., 2014). The common measurements of taste sensitivity are briefly described in the next section.

1.4.1. Detection threshold

The detection threshold is the lowest concentration at which taste compounds can be detected. Subjects often perceive the detection sensation as a hint of something that distinguishes the sample from the reference (Reed & Knaapila, 2010). At the detection level, subjects are not required to identify the taste modality (e.g., sweet, sour, salty). The reference used in the detection threshold depends on the samples. For example, in the case of a single tastant dissolved in water (to measure taste sensitivity), the reference will be the water, while in a food emulsion matrix with different fat content (to measure fattiness sensitivity) the reference will be the emulsion matrix without any fat addition. The measurement of detection threshold is regarded as relatively objective because it does not require the use of a subjective scale but rather uses an exact level of concentration at which subjects are able to detect the differences between the sample and the reference (Reed & Knaapila, 2010). The data obtained will be an absolute threshold, and children's subjective use of the scale is avoided.

The procedure for measuring a detection threshold require tasting of several samples and is very time-consuming (Joseph, Mennella, Cowart, & Pepino, 2021). A recent tracking threshold method proposed by Joseph et al. (2021) required 17 samples of tastant solution to be prepared prior to evaluate one taste modality only, even though not all solutions would be tasted by subjects. This test requires around 15 minutes per taste stimulus to be completed by adult subjects and around 75 minutes for all five basic tastes, which is very time-consuming. These two factors (the number of samples and amount of time needed) should be considered when the detection-threshold method is employed, especially when the panellist is a child. Reducing the number of samples or limiting the taste quality involvement in the study should be considered to reduce evaluation time in order to maintain the participant's focus and avoid fatigue.

1.4.2. Recognition threshold

The recognition threshold refers to the lowest concentration at which the taste stimulus can be correctly named for its quality (e.g., sweet, sour, salty, bitter, umami) (Reed & Knaapila, 2010). A recognition threshold is obtained at a higher concentration than the detection threshold (Chamoun et al., 2018). The recognition threshold also measures the absolute level at the exact concentration or level in which the taste modality is being correctly determined. Similar to the detection threshold, the use of the recognition threshold must be carefully considered because it is time-consuming and potentially fatiguing due to its requirement that the subject have to taste many samples.

1.4.3. Taste modality recognition

Taste modality is measured when subjects are asked to identify different taste stimuli (taste qualities). The difference between taste-recognition threshold and taste-modality recognition concerns the type of data collected. Unlike the taste-recognition threshold, in which a certain concentration level of a tastant can be obtained, the taste-modality recognition measurement does not change with higher concentration, as subjects are asked to identify the taste regardless of the concentration of tastant presented (Puputti, Aisala, Hoppu, & Sandell, 2018). Taste modality recognition does not require many concentration levels, while taste recognition threshold requires the subjects to evaluate different concentration levels of the tastant (Webb et al., 2015).

1.4.4. Taste intensity

Perceived intensity or taste responsiveness aims to measure taste sensitivity above the threshold levels (Chamoun et al., 2019). This method is also known as *suprathreshold intensity*. Unlike the detection and recognition thresholds, intensity perception provides information regarding the concentration level of tastant (i.e., weak, medium, strong) since subjects provide a response reflecting the perceived intensity of a stimulus using a scale. Different scales can be used to measure subjects' responses. According to Lawless and Heymann (2010), taste intensity perception is commonly recorded on a continuous line scale. Measuring taste intensity perception is more time-efficient compared to threshold, with a smaller number of samples to be tasted (Low, Lacy, McBride, & Keast, 2016). Moreover, according to Low et al. (2016), measuring intensity perception was more relevant to studying food liking and preferences because most tastants in foods are noticeable and perceived above their threshold levels. The perceived intensity of the same taste stimuli can vary across individuals (Webb et al., 2015); this has been investigated both in the adult population (Dinnella et al., 2018; Puputti, Aisala, Hoppu, & Sandell, 2019) and in preadolescent children (Alexy et al., 2011; Ervina, Berget, & Almli, 2020; Hartvig et al., 2014).

1.4.5. Responsiveness to PROP (6-n-propylthiouracyl)

Responsiveness to PROP specifically measures the subjects' intensity perception to PROP bitterness. PROP can be extremely bitter for some people, while others perceive little or no bitterness at all (Barthoshuk, 2000; Tepper, 2008). The subjects can be categorised into supertasters, medium tasters and non-tasters according to their intensity perception of PROP bitterness (Oftedal & Tepper, 2013), as measured using a standardised scale of LMS (Labelled Magnitude Scale) or gLMS (Generalised Labelled Magnitude Scale) (Bartoshuk et al., 2004; Green et al., 1996).

Subjects categorised as supertasters perceived a higher bitter sensation of PROP compared to medium tasters and non-tasters (Barthoshuk, 2000). Sensitivity to PROP is positively associated with the perceived intensity of other basic tastes (Ervina, Berget, & Almli, 2020; Fischer et al., 2014; Tepper et al., 2017); thus, PROP is commonly used as a general marker to study individual differences in taste-intensity perceptions (Keller & Adise, 2016; Tepper, 2008). PROP compound is chemically similar to phenylthiocarbamide (PTC), and sensitivity to this compound is significantly associated with TAS2R38 bitter receptors (Bufe et al., 2005; Dioszegi, Llanaj, & Adany, 2019).

1.4.6. Fungiform papillae count

Quantification of fungiform papillae is also considered as a method of measuring taste sensitivity (Dinnella et al., 2018; Webb et al., 2015). Subjects with high fungiform papillae density hypothetically will have a higher taste sensitivity because fungiform papillae contain taste buds that anatomically have a direct link with taste receptors (Zhang et al., 2009). Measuring fungiform papillae density directly measures the number of taste buds that are physiologically recognised as an important biological system in taste stimuli perceptions. However, there is a concern about using this method, as recent studies involving large population samples of adults concluded that fungiform papillae density did not directly correlate to taste sensitivity (Dinnella et al., 2018; Piochi et al., 2019). Moreover, taste buds in children are not fully developed in terms of their biological function (Correa, Hutchinson, Laing, & Jinks, 2013), which could be the reason that studies implementing papillae density count method did not show any associations with taste responsiveness or taste threshold in children (Jilani, Ahrens, et al., 2017). Fungiform papillae density was also reported to differ significantly across age groups (Fischer et al., 2013), and it could be extremely complex to collect data on fungiform papillae in preadolescent subjects using a remote testing setup. Therefore, this study did not include quantification of fungiform papillae.

1.4.7. Fattiness sensitivity

There are several ways to measure fattiness sensitivity, depending on the type of fatty acids in the lipid compound, concentrations, subjects and objectives of the study, as summarised by Heinze et al. (2015). Fattiness sensitivity can be measured using different approaches, such as detection threshold and intensity perception, for example using the 3-AFC (Three-Alternative Forced-Choice) test, rating or ranking (Haryono et al., 2014; Heinze et al., 2015). The advantages and disadvantages of each approach have been critically reviewed and discussed by Heinze et al. (2015). The 3-AFC method was suggested to be used in measuring fattiness sensitivity due to its reliability (Heinze et al., 2015). However, the use of the 3-AFC test can result in subjects suffering from fatigue as the test is time-consuming. In this study, the two-alternative forced choice method (2-AFC) was implemented. This method was chosen to eliminate the concern about subjects' getting fatigued during testing.

Using different types of fatty acid as samples in measuring fattiness sensitivity could results in different outcomes, as there is no global standard for what type of fatty acid should be used as the reference. Moreover, the use of free fatty acid (FFA) vs triacyl glyceride (TAG) as a taste compound in measuring fattiness sensitivity is still subject to debate, and each has advantages and disadvantages (Heinze et al., 2015). FFA able to provide a single molecule of fat, but FFA content in food is low because high FFA is associated with rancid or rotten foods. On the other hand, TAG is not a single molecule and requires enzymatic processes to break down into FFA, but fat in a food matrix is mostly based on TAG (Heinze et al., 2015). Therefore, measuring fattiness sensitivity based on FFA and TAG may generate different results that are difficult to compare, thus requiring more harmonisation in psychophysics method for fattiness perception. Different model food samples, such as milk, cheese or pudding varying in fat content, have been used to investigate fattiness sensitivity in the previous studies (Alexy et al., 2011; Mennella et al., 2012).

1.5. Factors affecting taste sensitivity

There are several factors that influence individual variations in taste perceptions. Factors that have been reported to affect taste sensitivity include physiological differences in gustatory systems, differences in cognitive processing of the different taste signals in the brain, genetic factors and environmental factors (Puputti et al., 2019). Specifically, these factors can be categorised as intrinsic or extrinsic factors. Intrinsic factors include gender, genetics, age and ethnicity (Barragan et al., 2018; Duffy & Bartoshuk, 2000; Joseph et al., 2016), while extrinsic factors comprise health- and disease-related factors (e.g., taking a specific medication, having specific diseases or weight status, such as obesity), family environmental factors, socio-demographic factors (e.g., socioeconomic conditions, parental education), peer influence, tastes, flavours and food exposure. Among these factors, three are related to this study: food exposure, age and gender. In addition, PROP responsiveness was also investigated in this study, and the phenotype groups obtained from PROP measurements have been shown to be associated with genetic determinants of certain taste receptors (Fischer et al., 2014; Sollai et al., 2017). Therefore, factors related to genetics will also be briefly discussed.

1.5.1. Food exposure

It has been hypothesised that subjects who are regularly exposed to certain tastes and flavours will have a higher acceptance of these tastes, which could be mediated by changes in their taste sensitivity (Nicklaus, 2016). A study by Mohd Nor, Houston-Price, Harvey, and Methven (2021) showed that there was a significant increase in the overall liking and intake for turnip over the repeated exposures investigated in 3–5-year-old children. Moreover, the familiarity aspects regarding how often children are exposed to eat certain foods were reported as one of critical factors in food acceptance (Nicklaus, 2016). A study by Vennerød, Almli, et al. (2017) demonstrated that children aged 4–5 years who were less sensitive to sweetness were also less frequently exposed to sweet foods, suggesting that food exposure may influence children's taste sensitivity. Kim and Lee (2009) also reported that frequent consumption of fast foods with high salt content was associated with decreasing saltiness sensitivity in 12–13-year-old children. These show that exposure to certain foods might be associated with taste sensitivity and food preferences in children.

1.5.2. Age

Taste sensitivity is significantly associated with age (Mojet, Christ-Hazelhof, & Heidema, 2005). Older people (60–75 years old) have a lower taste responsiveness and taste threshold compared to younger subjects (19–33 years old), this was observed for all basic taste modalities (Mojet et al., 2005). Some studies reported that children have poorer taste perception than adults due to their low ability to determine taste modalities in sensory testing (Baker, Didcock, Kemm, & Patrick, 1983; Guinard, 2000). Other studies, however, have demonstrated that children have a good ability to identify taste stimuli (Laing et al., 2008; Liem, Mars, & de Graaf, 2004). Children aged 5–7 years were reported to be able to identify the four common tastes of sweet, salty, sour and bitter in water solution samples (Laing et al., 2008). Joseph et al. (2016) reported that older children were more sensitive to sweetness than younger children, which was investigated in children aged 7–14 years using a detection threshold. A longitudinal study approach regarding taste sensitivity demonstrated that sweetness sensitivity decreased significantly from children aged 4 to 6, while sourness sensitivity increased significantly for the same age range (Vennerød et al., 2018). All these results demonstrate that age can significantly affect taste sensitivity.

1.5.3. Gender

According to Spence (2019), the gender effect in taste sensitivity is remarkable. Several studies have reported that women were more sensitive than men in their taste intensity perception and taste threshold (Dinnella et al., 2018; Duffy & Bartoshuk, 2000). However, gender differences in taste sensitivity remain controversial since the results of the previous studies have been contradicted (Heinze et al., 2015; Ohla & Lundstrom, 2013). A study by Ohla and Lundstrom (2013) suggested that the differences in chemosensory perception between men and women are mostly due to their different cognitive evaluation rather than their sensory sensitivity. By contrast, a large population study in adults showed that gender difference in taste intensity perception does exist, indicating that women were significantly more sensitive than men (Dinnella et al., 2018; Michon, O'Sullivan, Delahunty, & Kerry, 2009; Pingel, Ostwald, Pau, Hummel, & Just, 2010). A study regarding sweet detection threshold in children aged 7–14 years indicated a significant difference across gender, with girls having a higher sweetness sensitivity than boys (Joseph et al., 2016). The threshold and perceived intensity for sweet, salty, sour and umami in children aged 5–12 years, however, did not differ between boys and girls (Majorana et al., 2012). Rodrigues et al. (2020) also reported no gender differences based on their study in children aged 8–9 years regarding sweetness and bitterness detection thresholds.

1.5.4. Genetics

It has been known for decades that individuals vary in their sensitivity to bitter compounds that contain thioureas, such as PTC and PROP (Barthoshuk, 2000). An investigation of this phenomenon revealed that the differences of sensitivity to bitter compounds were related to the genetic variation across individuals (Prescott & Tepper, 2004). The different responses to PTC and PROP across individuals have become a reference for basic taste investigations that have focused on the relationship between basic taste sensitivity and genetic determinants (Drayna, 2005; Prescott & Tepper, 2004; Reed & Knaapila, 2010). Inter-individual differences in taste sensitivity correlate with the genetic response, as reported for sucrose detection threshold in 7–14-year-old children (Joseph et al., 2016). The results indicate that children with two bitter-sensitive alleles of the TAS2R38 variant could detect sucrose at a lower concentration level than the children without these alleles, suggesting a significant association between sweetness sensitivity and genetics. Moreover, variations in response to PROP are associated with food acceptance; subjects with a higher responsiveness to PROP have a lower acceptance of sweet and fatty foods (Duffy & Bartoshuk, 2000), while different PROP responsiveness are associated with genotyping of the TAS2R38 gene that encodes bitter taste receptors for PROP (Kim, Breslin, Reed, & Drayna, 2004). The genetic background of basic taste perception was reviewed by Dioszegi et al. (2019) for sweet, bitter and fatty taste perception and highlighted the individual sensitivity of these tastes in relation to TAS2R38 and CD36 responses.

1.6. Taste sensitivity, food preferences and liking in children

Several studies have addressed the relationships between taste sensitivity and food preferences or liking in children. Studies have involved infants less than one year old to investigate their acceptance of different basic tastes (Schwartz et al., 2017; Steiner et al., 2001). Some studies have been conducted to assess taste sensitivity and food preferences in preschoolers (Mohd Nor et al., 2021; Vennerød et al., 2018; Wendin, Prim, & Magnusson, 2017). The preschool years are considered as the peak period when food neophobia develops (Cooke, 2007; Dovey, Staples, Gibson, & Halford, 2008). Taste-sensitivity studies with a focus on food acceptances and preferences were also reported in preadolescents, but a limited number of studies was found compared to studies with preschoolers (Nicklaus, 2020). A large population study in children in Europe addressing taste sensitivity and preferences was conducted previously and known as the IDEFICS study (Ahrens, 2015). This study involved more than 1,800 children aged 6–9 years and concluded that children in this age group have a higher preference for relatively sweet, fatty and salty foods. This study also indicated that taste sensitivity for sweetness, saltiness, bitterness and umami varies highly across countries, suggesting a strong influence of socio-cultural and demographic factors on taste sensitivity (Ahrens, 2015). Other studies, however, reported different findings regarding taste sensitivity and food preferences investigated in child subjects; some are summarised in Table 1.

The different studies employed different methods to measure taste sensitivity or hedonic responses, resulting in different findings, as presented in Table 1. For example, Vennerød, Almli, et al. (2017) suggested a significant relationship between bitter taste sensitivity and food preferences, but this relationship was not found in the studies reported by Hartvig et al. (2014) or Ahrens (2015). This could be due to the different methods used in each study: for example, the different types or concentrations of tastants (4 levels, 5 levels or 5–6 levels of tastant concentration) or the different model foods used (e.g., beverages, chocolate, crackers, juice). Age differences could also contribute to the different findings since age has been reported to significantly influence taste sensitivity. Moreover, taste sensitivity in children has been associated with eating behaviour or BMI (Alexy et al., 2011; Stoner et al., 2019), as also presented in Table 1. Table 1 also shows that most studies in this area have focused on bitter and/or sweet taste, with few studies involving all five basic taste modalities and fattiness.

Table 1. Some reported studies on the associations among taste sensitivity, food preferences or liking and eating behaviour in children

Reference	**Subjects**	**Methods, taste compounds or food samples used**	**Target taste**	**Main findings**
Rodrigues et al. (2020)	387 children aged 8–9 years	• Detection threshold of five different concentration levels for sucrose (sweetness) and caffeine (bitterness) • Liking investigated in 36 different food items (questionnaire)	Bitter Sweet	• Children with low sensitivity to bitterness had a higher liking for raw carrots compared to children with high bitterness sensitivity • Children with low sweetness sensitivity like chocolate milk, fried potato and rice higher compared to children who were sensitive to sweetness
Vennerød, Almli, et al. (2017)	135 children aged 4–5 years	• Detection threshold of four concentration levels for sucrose (sweetness) and quinine (bitterness) • Children's preferences were investigated using flavoured drinks with three different sweetness levels (sweetness) and chocolate with three	Bitter Sweet	• The children who were less sensitive to sweetness preferred less sweetness in drinks • Bitter-sensitive children preferred less sweetness and more bitterness (higher cacao content) in chocolate

Reference	Subjects	Methods, taste compounds or food samples used	Target taste	Main findings
		different percentages of cacao level (bitterness)		
Keller, Steinmann, Nurse, and Tepper (2002)	67 children aged 4–5 years	• PROP responsiveness in water solution • Acceptance of raw and cooked broccoli, orange juice, grapefruit juice, milk chocolate and American cheese	Bitter	• The children who were highly responsive to PROP (tasters) had a lower acceptance of raw broccoli and American cheese compared to the children who were less responsive to PROP (non-tasters)
Wijtzes et al. (2017)	5,585 children aged 6 years	• PROP responsiveness in water solution • Preference for different food items (assessed by questionnaire using food pictures) for candy, chocolate, mayonnaise, whipped cream, soup, potato chips, carrots and bread (the food items selected aimed to represent basic tastes and fattiness)	Bitter	• Non-taster children had slightly higher preferences for carrots and bread • No differences were found between taster and non-taster groups regarding preferences for sweet, salty and fatty foods
Stoner et al. (2019)	342 children aged 8–10 years	• Taste sensitivity measured using a PROP paper strip • Children's anthropometries (BMI and Fat Mass Index (FMI)) were collected, and food consumption pattern was recorded in a questionnaire	Bitter	• No correlation was found between BMI and PROP status (taster vs non-taster) • Sensitivity to bitterness may mediate the relationship between food consumption pattern and body composition
Hartvig et al. (2014)	328 children aged 9–11 years	• Taste recognition level (taste identification ability) measured using six concentrations of quinine (bitterness) and five concentrations of citric acid (sourness), sucrose (sweetness) and sodium chloride (saltiness) • Children's acceptance of carrot juice, rosehip juice, sea-buckthorn juice, lingonberry juice, grapefruit juice and aronia (chokeberry) juice was measured (the juices were selected to represent sweet, sour, bitter and astringency)	Bitter Sweet Sour Salty	• No relationship was found between liking of the juices and sensitivity to bitter, sour, sweet and salty tastes • Children with high sensitivity to bitterness had a lower intake of grapefruit juice • Sensitivity to sour, sweet and salty tastes did not influence the intake of the juices
Alexy et al. (2011)	574 children aged 10–17 years	• Taste identification ability of two water solutions with different intensities of sucrose (sweet), salt (salty), citric acid (sour) was measured • Fattiness sensitivity was measured using two samples of milk differing in fat content (low vs high) • Children's preferences were measured in model foods differing in taste compounds	Sweet Salty Sour Fatty	• Most of the children preferred food samples with more intense tastes (samples with higher sucrose, salt, citric acid and fat) • No differences for taste sensitivity or food preferences were found across the different BMI (normal vs overweight or obese)

Reference	Subjects	Methods, taste compounds or food samples used	Target taste	Main findings
		(low vs high) using 2-AFC method. Apple juice (sucrose), cheese (salt), orange juice (citric acid), cheese and salami (fat) were evaluated • Children's BMI recorded		
Ahrens (2015)	1,839 children aged 6–9 years	• Detection threshold of five concentration levels of sucrose (sweetness), caffeine (bitterness), sodium chloride (saltiness), MSG (umami) was measured • Preference test measured model food samples with different taste compounds (low vs high), apple juice (sucrose) and crackers (salt, MSG, fat)	Sweet Salty Bitter Umami	• Basic taste sensitivity was highly affected by country effect • Children preferred food with higher intensities of sweet, salty and fatty tastes • Taste sensitivity did not correlate with taste preferences
Papantoni, Shearrer, Sadler, Stice, and Burger (2021)	105 children aged 14–16 years	• Children's taste sensitivity was measured using discrimination method of triangle test in model foods differing in taste compounds: beverages (sucrose), chocolate milk (fat) • Children's liking was measured in model food of milkshake varying in sugar and fat content	Sweet Fatty	• Sweetness sensitivity was negatively associated with the liking of high-sugar milkshakes • Fat sensitivity did not correlate with the liking of milkshakes

1.7. Preadolescence

Preadolescence is the period before adolescence, or when children are between 9 and 14 years old (Oftedal & Tepper, 2013). In this period, children are characterised by rapid growth and development. In addition, their body shape (i.e., weight, height), dieting concerns, food selections and eating behaviour begin to change (Houldcroft, Farrow, & Haycraft, 2014; Oftedal & Tepper, 2013). This period is also characterised by increasing independence and autonomy, as children begin to have more control over their decision about food choices and what they would like to eat. Their parents' feeding practices regarding their children may also change during this time to reflect their child's physiological and psychological changes (Houldcroft et al., 2014). Research suggests, however, that parents still have control over their child's eating behaviour since parents still act as the primary food providers at home until their child reaches adolescence (Houldcroft, Farrow, & Haycraft, 2016). Preadolescents were characterised as curious and autonomous eaters, yet they were still bound by parental food practices (Nicklaus, 2020).

It is important to build healthy eating behaviour during this period. Children who are overweight or obese during preadolescence have a high chance of remaining overweight or obese when they become adolescents, and this will continue until adulthood (Scaglioni et al., 2018). Moreover, preadolescents were reported to be at risk of becoming picky eaters (Viljakainen et al., 2019). Healthy food preferences and eating behaviours developed during this age will remain until children grow older and are expected to be sustained and implemented continuously until they reach adulthood (Nicklaus & Remy, 2013); therefore, it is crucial to build a healthy eating practice during this period.

1.8. Adapting sensory testing with preadolescent children

Children have different physical and cognitive abilities compared to adults, therefore a different sensory approach is required when conducting sensory testing with them (Guinard, 2000; Jilani, Peplies, & Buchecker, 2019; Popper & Kroll, 2005). A review study regarding sensory evaluation with school-age children suggested that 4–11-year-old children could perform most of the sensory evaluation methods if age-appropriate procedures were implemented (Laureati, Pagliarini, Toschi, & Monteleone, 2015). When children are involved in sensory evaluation, the test procedures should be easy and understandable, and the instructions should be simple, clear and easy to follow (Jilani et al., 2019). The test should be performed in the shortest possible time since children have a shorter attention span than adults (Guinard, 2000; Jilani et al., 2019). If the test requires a longer time, it is important to create a test that keeps children motivated to complete the whole procedures (Knof et al., 2011) or allows them to request a short break if needed (Guinard, 2000). These practices have been implemented to avoid children getting bored or fatigued during testing.

To attract and motivate children, a game-like approach in sensory testing was suggested (Jilani et al., 2019; Laureati & Pagliarini, 2018). A short story was reported to be able to maintain children's excitement and motivation to finish the whole sensory test and minimise dropout (Vennerød, Hersleth, Nicklaus, & Almli, 2017). A familiar environment, such as school, is preferred, rather than a sensory laboratory setting when running the sensory testing with children. In our study, we tried to implement these suggestions by implementing a gamification approach to the sensory testing. The game-like concept in this study was inspired by a study from Knof et al. (2011).

2. Research Objectives

The main objective of this thesis was to investigate the relationship between basic taste sensitivity and food liking in preadolescent children. Three studies were conducted to answer the main objective. The overview of the three studies, the research questions and the paper involved in each study are presented as follows:

<u>Study 1 (paper 1)</u>

Children's identification ability to different taste modalities were investigated, including the association between taste identification ability and liking patterns. Some questions were addressed in this study.

- Can preadolescent children distinguish different basic taste perception modalities in unfamiliar food samples?
- Is there an association between taste identification ability and liking of unfamiliar food in preadolescent children?

<u>Study 2 (papers 2 and 3)</u>

Study 2 aimed to investigate the relationships between taste sensitivity and food liking. The associations among children's taste sensitivity, eating behaviour and food propensity were also investigated using child–parent dyad responses. Fattiness-sensitivity measurement and two different bitter compounds were also involved.

- Do basic taste and fattiness sensitivity in preadolescent children affect their food liking of the selected food items? (paper 2)
- Are different taste-sensitivity measurements in preadolescent subjects correlated with one another? (paper 2)
- What are the associations among taste sensitivity, eating behaviour and food propensity in preadolescent children? (paper 3)
- Do different bitterness compounds (caffeine and quinine) elicit different sensitivities and liking perceptions in preadolescent subjects? (paper 2)

<u>Study 3 (paper 4)</u>

This study aimed to investigate the influence of taste responsiveness and liking in model food samples of preadolescent children. The relationships among individual differences in taste responsiveness and stated liking, familiarity, food choice and food neophobia were also explored.

- Does children's basic taste responsiveness affect their liking of model food samples (grapefruit juice and vegetable broth)?
- What are the relationships among basic taste responsiveness, food choice, food familiarity and neophobia in preadolescents?

The five basic taste modalities of sweet, sour, salty, bitter and umami were investigated in all studies except study 1, which excluded umami. The gender effect (girls vs boys) in children's taste sensitivity was also investigated in all studies, but the age effect was not investigated since participants were recruited from the same cohort with limited age gaps. PROP responsiveness was measured in studies 2 and 3, and the association between PROP and taste sensitivity was also explored.

3. Materials and Methods

3.1. General overview

The study was divided into three parts. The first study focused on taste identification ability and liking, and the data was collected in 2013. The second and third studies were focused on taste sensitivity and food liking, and the data were collected in 2019 and 2020, respectively. All subjects were preadolescent children between 9 and 14 years old. A total of 105, 118 and 165 children were invited to participate in studies 1, 2 and 3, respectively. All tests took place at the children's respective schools. A pre-test or pilot test was conducted prior to the evaluation with a selected number of children from a similar age group. This practice aimed to evaluate whether the method worked well with the targeted age group and determine the approximate time required to complete the entire test. Technical aspects, such as sample handling (preparation, distribution, serving), test setup (devices, questionnaire) and instructions to the children were also observed, evaluated and adjusted based on this pre- and/or pilot test.

The basic taste stimulus of a single tastant in water solution and in model foods was employed. Some of the concentration levels of the tastants were evaluated by the trained panellists at Nofima. For example, the concentrations of caffeine and quinine were evaluated to ensure that each concentration level had an equivalent bitterness intensity. In addition, the model food samples of grapefruit, vegetable broth, milk and the unfamiliar food samples used as taste carriers in this study were also pretested and evaluated by the trained panellists.

3.2. Recruitment and participants

The participants were recruited from local primary schools in Ski and Ås municipalities in the Viken region of Norway. Fifth-grade elementary children (10–11-year-old) were selected for the first study, while the second and third studies involved 6^{th} (11–12-year-old) and 7^{th} grade (12–13-year-old), respectively. Only children from the same cohort were invited into each study aimed to minimise age differences among subjects. Houldcroft et al. (2014) reported that children's autonomy, independence and cognitive levels were remarkably diverse in preadolescents aged 10–12 years. As previously described, taste sensitivity is significantly influenced by age, so we tried to minimise the age differences by recruiting children from the same cohort.

From the total numbers of the children invited, those who did not finish the test or had allergies to the food samples (i.e., did not taste the samples) were removed from the data, resulting in a total of 98, 106 and 148 participants for studies 1, 2 and 3, respectively. These numbers were further used for data analysis in the respective publications. Children's participation was voluntary, and a signed consent form from their parents was mandatory to join the study (see the Ethical Considerations section).

3.3. Tasted samples

The different samples, such as a single tastant in water solution, model foods (grapefruit juice, vegetable broth) and real foods (milk, unfamiliar foods), were employed.

3.3.1. Water solutions

The taste compounds (tastants) and concentration levels used in the water-solution samples (study 2) were adapted from a study by Knof et al. (2011). The same concentration of four basic tastes (sweet, salty, bitter, umami) were previously used in a large population study in 6–9-year-old children to measure their taste sensitivity (Ahrens, 2015). The compound and concentration levels for sourness were adapted from a study by Myhrer, Carlehog, and Hersleth (2016), while the bitter quinine was adapted from a study by Vennerød, Hersleth, et al. (2017). Five concentration levels for each basic taste were used (Table 2) and were piloted with 42 children aged 12–13 years. The results from this pilot test showed that the concentration levels covered a suitable concentration range for measuring the detection and recognition thresholds and matched one another for taste intensity at each concentration level. The sample solutions were prepared by dissolving the taste compounds in tap water for a maximum of two days before the experiment took place.

Table 2. Taste compounds and concentration levels of basic tastes (study 2)

Taste	Taste compound	Level 1 (g/l)	Level 2 (g/l)	Level 3 (g/l)	Level 4 (g/l)	level 5 (g/l)
Sweet	Sucrose	3.0	6.0	9.0	12.0	16.0
Sour	Citric acid	0.05	0.1	0.16	0.2	0.25
Salty	Sodium chloride	0.2	0.4	0.8	1.2	1.6
Umami	Monosodium glutamate	0.1	0.3	0.6	1.2	1.5
Bitter	Caffeine	0.05	0.1	0.15	0.2	0.27
Bitter	Quinine	0.0014	0.0017	0.0023	0.0038	0.006

3.3.2. Food samples

Different food samples were used as taste carriers in this study. The real (unfamiliar) foods were employed in the first study, while the model foods of grapefruit juice (added sucrose) and vegetable broth (added sodium chloride) were used to measure children's basic taste responsiveness in the third study. In addition, milk samples with different fat content were used to measure fattiness sensitivity in the second study.

The term *unfamiliar* foods used in the first study reflects foods that most of the children had never tasted. Nineteen unfamiliar food samples were evaluated by the children, who were asked to identify the dominant taste of each (Table 3). These unfamiliar food samples also needed to reflect the four basic tastes of sweet, sour, salty and bitter. Umami taste was excluded because the preliminary study indicated that children were unfamiliar with the term and the taste of umami itself in addition to the possibility of cross-modality with saltiness, which makes this taste difficult to determine. A trained panellist was involved in determining the dominant basic tastes for each food sample, and at least one or two dominant tastes were selected. The term *dominant taste* refers to the most striking taste sensation that occurred when tasting the samples (Pineau et al., 2009).

Table 3. Unfamiliar food samples used to evaluate taste identification ability in children (study 1)

Food Group	Food Samples	Dominant Taste
Dairy	Goat cheese	Sour
	Sour milk	Sour, bitter
Meat-based	Cocktail salami	Salty
	Chorizo	Salty, sweet
	Beef jerky	Salty, sweet
	Crab stick	Salty, sweet
Cereals	Durum wheat semolina	Sweet
	Bulgur	Sweet
Fruit and vegetables	Cucumber pickle	Sour
	Grapefruit	Sour, bitter
	Persimmon	Sweet
	Artichoke heart	Sour, salty
	Goji berry	Bitter
	Kumquat	Sour, bitter
	Water chestnut	Bitter
	Carrot juice	Sweet
Sweets	Coconut cubes	Sweet
	Root beer	Sweet
	Ginger candy	Sweet

Four milk samples (plain milk, TINE SA, Norway) varying in fat content (3.5%, 2%, 1% and 0.5% milk fat) were employed to measure children's fattiness sensitivity and hedonic responses. The milk samples were evaluated using a 2-AFC method (comparing low vs high fat content: 3.5% vs 2%, 2% vs 1%, and 1% vs 0.5%). The model foods of grapefruit juice and vegetable broth, modulated with four additional amounts of sucrose and sodium chloride, respectively, were selected as taste carriers for study 3 (Table 4). The addition of sucrose and sodium chloride aimed to elicit different taste-intensity sensations for each basic taste modality. Sweetness, sourness and bitterness were the target sensations in grapefruit juice, while saltiness and umami were evaluated in vegetable broth. The addition of sucrose in grapefruit juice aimed to gradually suppress the bitter and sour tastes naturally present in the juice while increasing sweetness intensity (Green, Lim, Osterhoff, Blacher, & Nachtigal, 2010). The addition of sodium chloride was expected to elicit saltiness in broth samples. The umami taste was also expected to be gradually increased by the presence of sodium chloride since these two tastes enhance each other and work synergically (Fuke & Ueda, 1996; Hartley, Liem, & Keast, 2019).

Table 4. The food samples and tastant additions (study 3)

Food samples	Tastant addition	Target sensations	Sample 1 (g/L)	Sample 2 (g/L)	Sample 3 (g/L)	Sample 4 (g/L)
Grapefruit juice	Sucrose	Sweetness Bitterness Sourness	0	40	80	160
Vegetable broth	Sodium chloride	Saltiness Umami	0	3	6	12

3.4. Food questionnaires

The children completed several food questionnaires. They provided their stated liking for 30 food items representing five basic tastes and fattiness modalities in the second study. The taste profiles of each food were categorised following the study from Martin, Visalli, Lange, Schlich, and Issanchou (2014). The different food liking questionnaires were also introduced in the third study. The children's stated liking towards 28 food items with different taste profiles was measured, focusing on sweetness, sourness and bitterness. The food items were fruits (10 items), vegetables (10 items), desserts and juices (8 items). In addition, the children were asked for their familiarity to these food items prior to evaluating their stated liking. Moreover, the children also completed a food-choice questionnaire consisting of 19 pairs of food items in the third study. The pairs represented foods that differed in their intensity of bitterness and sourness (lower vs higher), and children had to choose the food that they preferred between the pair (forced-choice method). Children's food neophobia was also measured using the Italian Child Food Neophobia Scale (ICFNS) that has been validated in different countries (Proserpio et al., 2020).

3.5. Parental questionnaires

The children's parents were given the Child Eating Behaviour Questionnaire (CEBQ) and the Food Propensity Questionnaire (FPQ). In addition, they provided the self-reported weight (kg) and height (cm) of their child to calculate their BMI. Information about parents' educational levels and food-related eating habits at home was also collected.

The CEBQ was adapted from a study by Wardle, Guthrie, Sanderson, and Rapoport (2001) consisting of 35 statements categorised into eight different domains: food responsiveness (FR, 5 items), enjoyment of food (EF, 4), emotional overeating (EOE, 4), desire to drink (DD, 3), satiety responsiveness (SR, 5), slowness in eating (SE, 4), emotional undereating (EUE, 4) and food fussiness (FF, 6). FR, EF, EOE and DD constitute the concept of 'food approach', while SR, SE, EUE and FF are associated with 'food avoidance' (Vandeweghe, Vervoort, Verbeken, Moens, & Braet, 2016). The CEBQ aimed to measure parent agreement with their child's eating behaviour at home. The previous studies reported that the CEBQ showed good reliability as an instrument to identify eating behaviour in children aged 5–12 years (Njardvik, Klar, & Thorsdottir, 2018; Quah et al., 2019). The CEBQ has also been used in different countries and shown good and consistent results in measuring children's eating behaviour (Sleddens, Kremers, & Thijs, 2008; Tay et al., 2016).

The FPQ consists of 83 food items divided into nine categories: 1) starchy foods (bread, pasta, rice and potato), 2) spread and sandwich filling ('*pålegg*' in Norwegian), 3) breakfast cereals, 4) milk and yoghurt, 5) warm and cold dishes (meat, fish, seafoods, soups), 6) vegetables, 7) fruits and berries, 8) dessert, cake, snacks and sweets and 9) drinks. The food list was adapted from the national dietary survey in Norway (Totland et al., 2012) and was then classified according to basic taste profiles following a database of different food items evaluated by trained panellists developed by Martin et al. (2014). The FPQ was recorded on a six-point scale of eating frequency, then converted into daily consumption equivalence scores (DCES) (Laureati et al., 2020).

3.6. Testing procedures

3.6.1. Gamification of 'taste detective games' in sensory testing

The tests were gamified in an activity called 'The Taste Detective Game' (Figure 2). The gamification aimed to make the activities fun and interesting for the children and increase their participation rate. Implementing a gamification concept in sensory testing with children was suggested by Jilani et al. (2019) to make sensory testing easy for them to understand. Moreover, it is important to design a test that motivates children to complete the whole testing procedure and minimise dropout, especially when the test takes a long time (Knof et al., 2011).

Figure 2. Screenshot of The Taste Detective Game in the online platform (translated from Norwegian)

3.6.2. Remote sensory testing

Remote sensory testing was employed for the third study (data collection was carried out between September and November 2020). It was not possible to meet physically with children at that time due to the Covid-19 pandemic. The sensory test was performed remotely with the children evaluated the food samples at their respective schools, while the instructions were provided live via video conference call. Figure 3 shows the preparation of the class for the remote test and the live instruction from the experimenter via a screen. The children and teacher could interact with the instructors and ask questions directly through a video conference call throughout the entire test. This remote sensory test was also gamified with the same concept of 'The Taste Detective Game'.

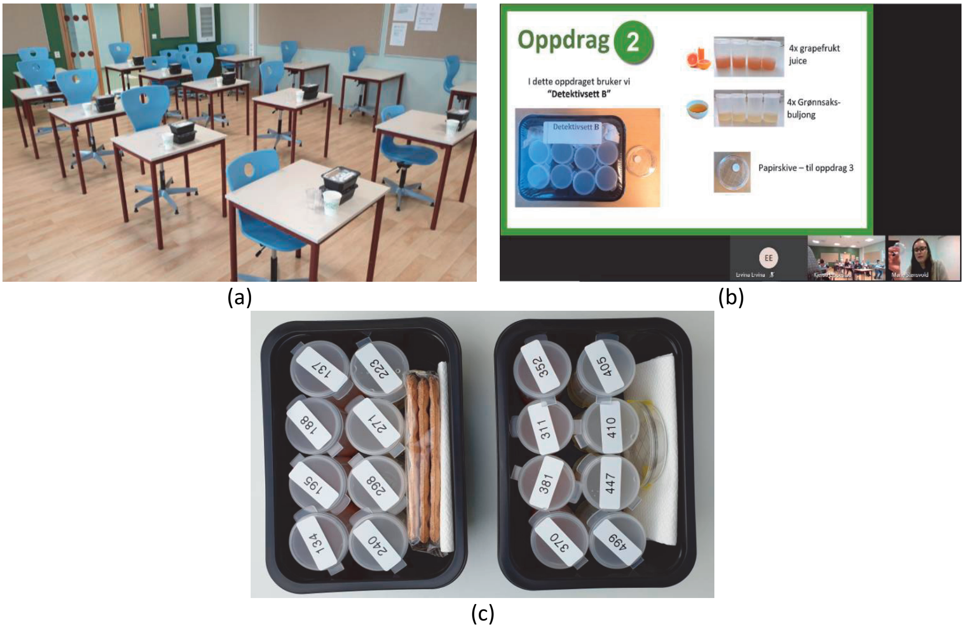

Figure 3. The classroom setting during remote testing, with (a) the distance between children's tables, (b) the remote instruction to the children using a PowerPoint presentation via video conference call and (c) boxes of food samples delivered to the children's schools.

3.7. Ethical consideration

All the studies were approved by the Norwegian Centre for Research Data (NSD). Parents or guardians were obligated to sign a consent form for their child to participate. The children also needed to sign the consent form in addition to a verbal consent that was asked prior to the evaluation. The children were told that they could withdraw from the test at any time without consequences. We also emphasised that all the tests were voluntary, without any enforcement of participation. The schools received a gift for the children's participation, and the tests were conducted as class activities during school hours. Those who did not have a signed consent form from their parents were separated during the testing time and assigned something else to do by their teacher. All the studies followed the Declaration of Helsinki, and all data-protection measures strictly followed the General Data Protection Regulation (GDPR).

3.8. Data analyses

Different multivariate approaches, such as CA (Correspondence Analysis), PCA (Principal Component Analysis) and MFA (Multiple Factor Analysis), were implemented in the data analysis to investigate the relationships among the variables of interest. Moreover, ANOVA (Analysis of Variance) was computed if the model involved one dependent variable and several qualitative groups (e.g., taste sensitivity groups, liking groups). All data analyses were computed using XLSTAT Sensory version (Addinsoft, Paris, France). The significant difference tests were calculated at a 95% confidence interval level ($p<0.05$), and Tukey's *post hoc* test was applied for pairwise comparison between groups.

4. Summary of Papers and Findings

A summary of each paper and an overview of the research's findings are presented below. The findings will be discussed in the next chapter.

4.1. Summary of papers

4.1.1. Paper 1

Paper 1 investigated whether preadolescent children could discriminate different basic taste modalities. This study also aimed to evaluate the association between children's taste identification ability and their liking of unfamiliar food samples. The familiarity exclusion in the food samples (unfamiliar foods) aimed to remove children's expectations and taste memories associated with the foods. By removing these factors, children were expected to depend solely on their taste-sensitivity perception. The results show that children had good congruency in identifying the basic tastes of sweet, sour, salty and bitter to the same degree as the trained panel. Their taste-identification ability was higher in sweet taste, especially when sweet taste appeared as a single dominant taste sensation and lower when there was more than one dominant taste sensation. No significant pattern was found between taste-identification ability and liking. Moreover, sweetness was shown to be the most liked taste in unfamiliar foods, while sourness and bitterness demonstrated a negative relationship with liking.

4.1.2. Paper 2

Paper 2 aimed to investigate the relationships among basic taste sensitivity, fattiness sensitivity and food liking in preadolescent children. Different methods (detection and recognition threshold, taste responsiveness and PROP responsiveness) were employed to measure children's taste sensitivity. The relationships among these different taste-sensitivity measurements were also investigated. A single basic taste compound dissolved in a water solution was used as a sample to measure children's taste sensitivity. In addition, two bitter compounds of caffeine and quinine were involved in this study. Fattiness sensitivity was also measured using milk samples whose fat content varied.

Positive correlations were found between detection and recognition threshold and between taste and PROP responsiveness. There was no significant influence of basic taste sensitivity on stated liking for the selected food items, food liking was significantly affected by different taste modalities. Sweet and fatty foods were the most liked, while bitter and umami foods were the least liked by preadolescent subjects. Fattiness sensitivity influenced liking, indicating that children with low sensitivity to fattiness preferred milk with higher fat content and had a higher liking for fatty foods. The results indicate that boys had a higher detection threshold (i.e., were less sensitive) compared to girls for sweetness and bitterness. Additionally, sensitivity and liking perception of the two bitter compounds of caffeine and quinine were shown to differ.

4.1.3. Paper 3

The objective of paper 3 was to investigate the associations among children's basic taste sensitivity, eating behaviour based on CEBQ and food propensity. Child–parent dyad data were used to investigate these relationships. Taste sensitivity was associated with eating behaviour in food responsiveness, emotional overeating and desire to drink. Children with less sensitivity to caffeine bitterness had a higher score in taste responsiveness, while children who were less sensitive to sweetness and caffeine bitterness had a higher score in emotional overeating. In addition, children who were less sensitive to sourness and to both caffeine and quinine bitterness had a higher score in their desire to drink. There were no relationships between children's taste sensitivity and food propensity in general for each taste, nor between taste sensitivity and propensity for dairy foods. However, propensity for dairy food did differ according to children's BMI, indicating that overweight or obese children had a higher frequency consumption of low-fat milk, and they were also less frequent in consuming flavoured milk, fermented milk, skimmed milk and cheese compared to the normal-weight children. There was no association between children's taste sensitivity and their BMI. BMI was positively associated with the food approach and negatively associated with food avoidance of CEBQ, based on the PCA results.

4.1.4. Paper 4

Paper 4 investigated the relationships between children's basic tastes sensitivity and their liking measured in model foods of grapefruit juice and vegetable broth. The model foods were varied with four additions of sucrose (grapefruit juice) and sodium chloride (vegetable broth). The subjects were clustered according to their individual differences in basic taste responsiveness; four clusters were formed with distinct taste responsiveness profiles. The results show that different clusters and sucrose concentrations significantly influenced liking in grapefruit juice, while no significant effect was found for clusters and sodium chloride concentrations on the liking of vegetable broth. The cluster characterised by children who were highly responsive to bitter and sour tastes and who were low responsiveness to sweet taste had a lower liking score of grapefruit juice compared to the other clusters. Moreover, the increase in liking was positively associated with the increase of sucrose concentration only in the cluster characterised by low responsiveness to bitter and sour tastes.

The results also revealed that changes in tastant concentrations significantly induced taste-intensity perception for sweetness, sourness and bitterness in the cluster with high responsiveness to basic tastes. This indicates that highly responsive children were more sensitive to changing their intensity responsiveness according to the change in tastant concentration. In addition, there were no systematic patterns found between taste-responsiveness clusters and stated liking, food choice, food familiarity or neophobia.

4.2. Result overview

There was a significant influence of preadolescents' taste sensitivity on their food liking, as measured by intensity perception in the model food samples of grapefruit juice. The same trend was not found in vegetable broth, indicating that the relationships between taste sensitivity and liking were product- and taste-dependent as well as subject-dependent. Fattiness sensitivity was also shown to influence the stated liking of the selected fatty foods. Preadolescent children were able to distinguish different basic taste modalities, with the caveat that a short training is suggested to familiarise them to basic tastes, especially for umami. No association was found between taste sensitivity and food liking when children's taste sensitivity was measured using water-solution samples and their liking was measured as stated liking (study 2). We also found no systematic association between taste sensitivity, as measured by taste-identification ability and liking of unfamiliar food samples (study 1). These results indicate that the different measurements and samples used may produce different results. The different measurements of taste sensitivity involved in this study were shown to be correlated with one another except between PROP responsiveness and recognition threshold level. All the correlations found, however, appear weak.

Our research found gender differences based on detection threshold, showing that boys have a higher detection threshold than girls for sweetness and bitterness. However, this association was not found in taste intensity perception suggesting that the different methods of measuring taste sensitivity in children may result in different conclusions regarding the gender effect. Interestingly, there were inter-individual differences in the bitterness of caffeine and quinine in terms of bitter taste intensity and liking perception, and these differences may be associated with some eating-behaviour aspects based on the CEBQ measurement. This study also confirmed higher preferences for pleasant tastes, such as sweetness and fattiness, and low preferences for warning tastes, such as bitterness and sourness, in preadolescent children. These associations were found to be persistent in unfamiliar food samples. There were no systematic associations found among children's taste sensitivity, food choice, familiarity or neophobia, indicating that these variables were not strongly correlated with taste sensitivity.

5. Discussion

5.1. The relationships between taste sensitivity and food liking

Our research highlights the significant influence of children's taste responsiveness to sweetness, bitterness and sourness on their liking of grapefruit juice (Ervina et al., 2021). Children who were highly responsive to bitterness and sourness or had low responsiveness to sweetness had a lower liking score for grapefruit juice. In addition, children with the lowest responsiveness to bitterness and sourness increased their liking of grapefruit juice in parallel with the sucrose addition. This shows that taste sensitivity significantly influences liking. Bitter and sour tastes are associated with food aversion (Mennella & Bobowski, 2015; Reed & Knaapila, 2010), while sweet taste is associated with food acceptance (Mennella & Bobowski, 2015). Children with low sensitivity to sweet taste might not perceive enough sweetness intensity, resulting in a low liking score. In addition, children who were highly responsive to bitterness and sourness perceived these tastes as intense no matter how much sucrose was added to mask the bitter and sour tastes in the samples. Based on our first study, the children's liking of unfamiliar foods was positively associated with sweet taste and negatively associated with sour and bitter tastes (Ervina, Berget, Nilsen, & Almli, 2020), indicating a biological motivation to like sweet and reject sour and bitter tastes in preadolescent children. Studies 2 and 3 showed similar patterns in taste preferences.

Our results also demonstrate that children with low responsiveness to all basic tastes significantly increased their liking score in parallel with the increase of sucrose concentrations in grapefruit juice, while highly responsive children had a small variation in their hedonic responses and already had a high liking score even of the sample with a low sucrose concentration. This may relate to the suppression effect, as reported in study 3 (Ervina et al., 2021), and suggests that the children with low responsiveness may be more susceptible to the overconsumption of food with high sugar content (i.e., high sweetness intensity), which makes them more prone to develop overweight or obesity. Our results support the previous studies showing that subjects with low taste sensitivity prefer foods with a high concentration of that particular tastant in order to 'meet' their optimum hedonic level (Cox et al., 2016; Mennella, Nolden, & Bobowski, 2018; Papantoni et al., 2021). Moreover, children with low sensitivity to basic tastes have a strong suppression effect on bitterness intensity and at the same time increase their sweetness intensity perception with the addition of sucrose. They also had the lowest responsiveness score for sourness and bitterness, meaning that they did not perceive these aversion tastes as intense, thus explaining the significant increase in their liking of grapefruit juice samples across the sucrose additions. The different taste-responsiveness in preadolescent children significantly induced variations in taste-intensity perception, resulting in different hedonic responses. This association was clearly seen in the case of the model food sample of grapefruit juice.

Despite the clear association between responsiveness to sweetness, sourness and bitterness and liking in grapefruit juice, there was no significant influence of saltiness or umami responsiveness on vegetable broth liking. This suggests that relationships between taste sensitivity and liking could be taste- and product-dependent in addition to being subject-dependent. Another reason could be the ecological validity of broth samples, because the samples were evaluated cold, and it is uncommon to 'drink' cold broth in a meal setting. In addition, the broth itself already contained sodium chloride as a base, and the addition of salt increases saltiness intensity further (22 g/L for the saltiest sample), which resulted in little variation for saltiness-intensity perception due to a salt content that was too high. Moreover, umami and salty tastes were evaluated in the same model food, which may create confusion when distinguishing between these two taste modalities. Umami has been reported as the most unfamiliar taste in children aged 7–11 years, and children may confuse this taste with salty or bitter at certain concentrations (Keast & Breslin, 2003; Mustonen et al., 2009).

The results also indicate that highly responsive children were more sensitive to changes in tastant concentrations. This corroborates the previous study reported by Piochi, Dinnella, Spinelli, Monteleone, and Torri (2021) in an adult population showed that subjects with high sensitivity were more likely to notice slight differences in tastant concentrations compared to low-sensitivity subjects. This finding could be translated into reformulation strategies for children's food products. For example, in the case of sugar reduction, this strategy should be carefully conducted, and sweetness intensity needs to be compensated to maintain the acceptability of the new reformulated sugar-reduced products by highly sensitive children.

Our study shows that children with low fattiness sensitivity tend to prefer high-fat milk and also have a higher liking score for selected fatty foods than children with high fattiness sensitivity. Fat could enhance palatability because it can provide a 'rich' taste and could enhance acceptability and intake. The association between fattiness sensitivity and food preferences in children has been investigated previously (Cox et al., 2016). A higher preference for fattiness could be due to the close correlation between this taste and sweetness or saltiness in foods (in the case of sweet–fatty or salty–fatty foods), and these type of foods have been shown to be the most preferred foods in preadolescent children (Ervina, Berget, & Almli, 2020).

Furthermore, the results from study 2 provide different results, indicating that food liking is poorly correlated to basic taste sensitivity. Children's food liking was shown to be strongly influenced by different taste modalities and not by taste sensitivity. The different results obtained between studies 2 and 3 might be due to the different samples used to measure taste sensitivity (water solutions vs model food samples). The use of 'real' food samples was recommended over water solutions (Dea et al., 2013) due to the relevance of the food context. Moreover, taste compounds are perceived differently when incorporated into a food matrix or water (Hayes & Johnson, 2017). Additionally, in study 2, children's hedonic responses were recorded as their stated liking for the selected food names without actual tasting, while in study 3 both children's hedonic responses and their taste sensitivities were measured in a real food matrix with actual tasting. This may contribute to the different results obtained. We also investigated the association between taste responsiveness clusters and stated liking in study 3, but no significant relationship was found. Taste perceptions in children are highly influenced by the eating context (Laureati & Pagliarini, 2019) and their previous food memories (Higgs, 2011). Different contextual aspects, such as how the foods were usually prepared and cooked or the occasions on which or with whom they had previously eaten the foods, could significantly affect children's food perceptions and liking. Therefore, asking food names without tasting could simultaneously direct children into different contexts according to their food habits and memories, thus may potentially influencing the overall results.

No significant associations were found between taste sensitivity and children's food choice, familiarity or food neophobia, indicating that there are no systematic relationships among these variables. Indeed, preferences in preadolescents could not be shaped solely by taste sensitivity. Extrinsic factors, such as family and cultural background, social-economic conditions and food exposure, could significantly influence food preferences in preadolescents (Boesveldt et al., 2018; Jilani, Intemann, et al., 2017), and none of these factors were investigated here. Moreover, peer influence has been reported to strongly affect food preferences and eating behaviour in this age group (Rageliene & Gronhoj, 2020). In addition, Mennella, Reiter, and Daniels (2016) suggested that food preferences are very 'plastic' and that extrinsic factors, rather than biological factors like taste sensitivity, could have a strong influence on food preferences. Kershaw and Mattes (2018), in agreement with this statement, concluded that the effect of taste sensitivity was weaker compared to environmental, exposure and cultural factors in determining food selections.

5.2. Associations between taste sensitivity and eating behaviour

Our study found significant associations between children's taste sensitivity and eating behaviour. This association was significant in food responsiveness, emotional overeating and desire to drink (Ervina et al., paper 3). The association between low sensitivity to bitterness and high food responsiveness may occur because children lose their barriers to bitter sensitivity and thus resulting in them to eat more. Bitterness is highly associated with food aversion in children (Mennella & Bobowski, 2015; Reed & Knaapila, 2010), and when sensitivity to this taste is lowered, it may decrease food aversion and therefore increase food intake. The results were also in line with the previous study by Goldstein et al. (2007), which demonstrated that 9-year-old children with low sensitivity to PROP bitterness had a higher energy intake than those who were highly sensitive to bitter taste.

Children with low sensitivity to sweetness and caffeine bitterness have a higher emotional overeating score (Ervina et al., paper 3). This association could be explained because negative emotion precedes the consumption of 'comfort food' which often characterised by sweet and fatty foods (van Strien et al., 2013). Negative emotion also modulates willingness to eat, and subjects with emotional eating attitudes cope with their negative feelings by eating comfort foods to lift their moods (Adam & Epel, 2007;

Macht, 2008; Michels et al., 2012). A study involving children aged 5–12 years concluded that eating due to negative emotions was significantly correlated with sweet food consumption (Michels et al., 2012), which may be associated with the sweetness sensitivity found in our study. Sensitivity to caffeine bitterness was also shown to be associated with emotional overeating. Several studies have reported that children with low bitterness sensitivity had higher food intake (Goldstein et al., 2007; Keller & Adise, 2016), and one factor that could increase food intake could be modulated by negative emotions (Hill, Moss, Sykes-Muskett, Conner, & O'Connor, 2018; Macht, 2008; Michels et al., 2012).

Sensitivity to sourness and caffeine and quinine bitterness were negatively associated with desire to drink. Our finding corroborates a previous study that demonstrated that 5–10-year-old children who were not sensitive to PROP bitterness had a higher preference for sweet beverages, soft drinks and more sugar added to their cereals and beverages (Mennella, Pepino, & Reed, 2005). Regarding the association between sourness and desire to drink, thirst regulation shares the same receptor with sourness sensitivity perception (Bichet, 2018; Gravina et al., 2013), which could be one of the underlying reasons for the significant relationship found here.

5.3. The relationships between children's basic taste sensitivity, food propensity, and BMI

There was no significant influence of children's taste sensitivity on food propensity found in our study. However, children's food propensity for dairy food differed across BMI groups (normal vs overweight/obese). The overweight/obese children had a significantly higher frequency consumption of low-fat milk, and less frequently consumed flavoured milk, fermented milk, skimmed milk and semi-hard type cheeses compared to normal-weight subjects. The Norwegian Health Authorities (2016) recommend consuming low-fat milk (0.5–1.8% fat content). Moreover, the higher frequency consumption of low-fat milk in overweight/obese children could be influenced by their parents, since almost 80% of the parents who participated in the study had a relatively high education level (bachelor's degree or higher). Parents' education has been reported to be associated with children's diet quality, which is related to low-fat and low-sugar diets (Cribb, Jones, Rogers, Ness, & Emmett, 2011; van Ansem, Schrijvers, Rodenburg, & van de Mheen, 2014). This could be the reason overweight/obese children have a lower frequency consumption of flavoured milk and semi-hard cheeses, since these products are considered to have high sugar (flavoured milk) or high fat (semi-hard cheeses) and parents would like to cut their child's intake of these foods, especially when their child is overweight or obese. According to Gahagan (2012), in families with obese children, parents have extra control over their children's food intake to reduce the children's weight. In addition, a recent study reported by Vanderhout et al. (2020) suggested that a higher intake of whole milk may be associated with lower adiposity in children.

There was no significant influence of taste sensitivity on children's BMI, but the food-approach domain of CEBQ was positively associated with BMI, while food avoidance was negatively correlated. These results verify the previous studies using the same CEBQ instruments to measure children's eating behaviour (Sanchez, Weisstaub, Santos, Corvalan, & Uauy, 2016; Webber, Hill, Saxton, Van Jaarsveld, & Wardle, 2009).

5.4. The relationships between taste-sensitivity measurements of preadolescents

Significant correlations among the different taste-sensitivity measurements (detection threshold, recognition threshold, taste intensity perception and PROP responsiveness) were observed in our study. The results obtained corroborate previous studies involving adult subjects (Chamoun et al., 2019; Webb et al., 2015). These correlations, however, appear weak (Pearson correlations between -0.1 to 0.30) which are aligned with the previous studies (Chamoun et al., 2019; Keast & Roper, 2007; Mojet et al., 2005). The weak relationships indicate that different methods may capture different aspects of taste perception (Keast & Roper, 2007). This could be one of the reasons that we might generate different results from different taste sensitivity measurements.

Based on our findings, taste responsiveness could differentiate the taste-sensitivity responses of preadolescent children compared to the other measurements. However, this may be due to methodological concerns since the detection and recognition thresholds were measured by only five levels of concentrations. The total number of samples used in this study are way below the total number of samples suggested by Joseph et al. (2021) which involved 17 different concentrations to assess the taste detection threshold. Moreover, the number of samples used to measure recognition threshold were also lower than the ISO recommendation of eight samples (ISO, 2011).

According to Snyder, Prescott, and Bartoshuk (2006), the suprathreshold measurement captures a more realistic picture of oral sensory function, and this method has been used in chemosensory testing for clinical diagnosis. Suprathreshold intensity scales also provide a more complete picture of oral sensory function than threshold alone, especially in food tasting, because the sensory experience of taste in food is always above the threshold level. A subject can judge whether a food is too salty, too sweet or just right in a continuous way (through strong or weak responses) rather than just as a binary (present and not present). This makes suprathreshold measurement more relevant to apply to studying taste sensitivity and its relation to preferences in a food context. Suprathreshold responses, however, must be recorded on a scale, so the use of scale should be considered when children are involved as panellists because the use of the scale by children could be highly subjective. Children have limited ability to understand a complex scaling concept (Lawless & Heymann, 2010); therefore, the use of simple scaling, a short explanation and training regarding the scales prior to the evaluations is recommended. On the other hand, threshold measurement does not depend on children's ability to use the scale properly, so threshold method can thus objectively measure taste sensitivity.

5.5. Inter-individual differences in bitterness sensitivity

The results show that children have different perceptions of intensity and liking of bitterness from different bitter compounds (caffeine and quinine). Bitter taste has the most varied compounds, including flavonoids, amino acids and alkaloids, that generate bitterness (Briand & Salles, 2016; Mennella & Bobowski, 2015). Moreover, each bitter compound has a different bitterness profile (Jane & Noble, 1986; Kamerud & Delwiche, 2007; Yokomukai, Cowart, & Beauchamp, 1993) and varying ability to stimulate bitter receptors at the genetic and molecular levels, resulting in different intensity perceptions for this taste (Meyerhof et al., 2010; Roura et al., 2015). Our results found significant associations between food responsiveness and emotional overeating with sensitivity to caffeine bitterness but not with sensitivity to quinine bitterness. This indicates that different bitter compounds may have different pathways in responding to a certain eating behaviour aspect, which could be related to bitterness-sensitivity responses to various bitter compounds. Moreover, caffeine and quinine are not distributed in the same foods (Mennella & Bobowski, 2015; Poole & Tordoff, 2017), which may contribute to their different bitterness perceptions.

5.6. Gender effect in taste sensitivity of preadolescent children

Our study records a gender effect in taste sensitivity for the detection threshold. The difference across gender was significant for sweetness and bitterness, demonstrating that boys have a higher detection threshold (i.e., are less sensitive) compared to girls. This result corroborates previous studies, which reported a higher detection threshold for sweetness in boys than in girls among children aged 13–15 years (Ashi et al., 2017) and 7–14 years (Joseph et al., 2016). According to Spence (2019), individual differences in sensory sensitivity and hedonic perceptions could be differentiated on a gender basis due to biological differences between men and women. There were also more supertasters among women than men (34% vs 22%), indicating that women were more taste-sensitive than men. A study investigating differences in taste-intensity perception based on gender showed that women were more sensitive than men for all taste modalities (Barragan et al., 2018; Michon et al., 2009).

However, no gender effect was found in taste intensity rating neither measures in water solution nor in model food samples. In addition, taste-modality recognition also showed no differences across gender. Ohla and Lundstrom (2013) hypothesised that gender differences for chemosensory stimuli were predominantly mediated by differences in cognitive or emotional appraisal rather than sensory sensitivity *per se*. Their study also indicated similar responses between men and women with regard to sensory sensitivity, anxiety and autonomous physiological responses, suggesting that the differences in sensory-sensitivity perception among gender could be more related to cognitive evaluation than biological differences in sensory sensitivity (Ohla & Lundstrom, 2013). This study was conducted in adults, however, and used only odorants to measure sensory sensitivity. Different results might occur if preadolescent subjects were involved and if both odorants and tastants were investigated since gustatory (taste) and olfactory (smell) functions are built by different systems (Richard, 2015). Gender differences in children's taste sensitivity are still subject to debate; some studies reported that girls tended to be more sensitive than boys (Ashi et al., 2017; Joseph et al., 2016), but other studies observed no gender effect at all (Hartvig et al., 2014; James, Laing, & Oram, 1997; Vennerød, Almli, et al., 2017). We suggest that the different methods of measuring taste sensitivity could influence the results regarding gender effect in taste sensitivity.

5.7. Practical implications

Based on our results, preadolescents' taste intensity perceptions were diverse, and this diversity was shown to influence their liking responses. The addition of sucrose to grapefruit juice did not significantly induce bitterness or sourness intensity in children who were characterised by high responsiveness to these tastes. Moreover, their sweetness-intensity perceptions remained low even after the highest addition of sucrose (160 g/L, GF160). On the other hand, children with high responsiveness to sweet taste already had a high intensity perception for this taste in the sample without the sucrose addition (0 g/L, GF0). This shows that the suppression effects of sucrose (sweetness) on the intensity perceptions of bitterness and sourness are highly dependent on children's taste responsiveness. In the strategies to improve children's acceptance of foods characterised by bitter and sour tastes, such as vegetables and fruits, masking strategies to suppress bitter and sour tastes might or might not be effective depending on children's taste-sensitivity characteristics. For example, the addition of sugar (sweetness) to mask bitterness in vegetables may be less effective in children characterised by high responsiveness to bitter taste, so other strategies, such as repeated exposure (Mohd Nor et al., 2021; Nicklaus, 2016), may be required.

This study could also be implemented in reformulation strategies in children's food products. For example, in the case of sugar reduction, producers should be careful about gradually reducing sugar content and compensating for the sweetness intensity of the reformulated products, since children with high taste sensitivity may significantly detect the changes, and this could result in a rejection of the new reduced-sugar product. Moreover, as suggested by Velazquez, Vidal, Varela, and Ares (2020) based on their study, a cross-modal interaction approach could support reformulating children's food products, and this method could be applied to overcome the low acceptability of foods due to differences in taste sensitivity.

The importance of individual differences in driving food preference and choice has been addressed previously (Ahrens, 2015; Monteleone et al., 2017) and this topic has been gaining more awareness in recent years, which calls for sensory-driven solutions that are personalised specifically for the needs of vulnerable groups, such as obese children, to shape their food preferences and choices towards healthy eating. Nevertheless, food preference is shaped not only by taste sensitivity; other extrinsic factors have also been reported to strongly influence food preferences in children (Boesveldt et al., 2018; Jilani, Intemann, et al., 2017; Mohd Nor et al., 2021). Therefore, strategy development to improve healthy food acceptance cannot depend on taste sensitivity perception alone. Knowledge gained in taste and hedonic perceptions, however, could support interpretations of food-related behaviour aimed at improving children's healthy eating. This approach should be communicated with professionals and public bodies to establish an effective intervention of healthy eating strategies for preadolescents, considering their individual differences to taste stimuli.

5.8. Methodological considerations and study limitations

Despite this study's strength of employing different methods to measure children's taste sensitivity, involving a complete set of five different basic tastes (sweetness, sourness, saltiness, bitterness and umami), including fattiness and the use of different matrices as taste carriers, some limitations of this study must be acknowledged. Some methodological considerations, including study limitations, will be addressed and further explained.

5.8.1. Type of taste compounds and concentration levels

The tastants used in this study have been commonly used previously to measure taste sensitivity in children. The same tastants were also used as a standard to measure taste sensitivity according to the International Standard Organisation No. 3972 (ISO, 2011). Taste sensitivity, however, depends on the type and concentration level of the tastant (Tiefenbacher, 2017). Our study confirms the different bitterness sensitivities evaluated in different bitter compounds (caffeine, quinine) indicating that various compounds that represent the same taste modality (bitterness) generated different intensity perceptions. Another example, measuring sweetness sensitivity perception using fructose, lactose or maltose instead of sucrose, generates different results because these compounds have different sweetness-intensity levels

(Tiefenbacher, 2017). Therefore, the selection of taste compounds in a taste-sensitivity study must be carefully considered despite their common taste modalities. Moreover, taste sensitivity is concentration-dependent: different concentration of tastants may result in different perceptions. For example, a low concentration of sour can be perceived as bitter (Breslin, 1996), and umami can be perceived as salty at low concentration or bitter at high concentration (Keast & Breslin, 2003; Roininen, Lähteenmäki, & Tuorilla, 1996).

5.8.2. Taste carrier: water solutions vs real food samples

In our study, different results were obtained when the water solutions or model food samples were employed as taste carriers. A study by Dea et al. (2013) suggested using a real food matrix as a taste carrier to study taste-sensitivity perception rather than water-solution samples. Dea and colleagues reported that the taste quality and intensity of bitter limonin and nomilin varied significantly when the compounds were tested in a water solution or a food matrix of fruit juice, indicating that the carrier used to dissolve the taste compounds significantly influenced taste perceptions. Hayes and Johnson (2017) also supported the use of real food samples to study human taste perception because in the eating context, people do not generally consume salt or sugar in water. Taste compounds are mostly mixed in a food matrix and consumed together with foods. The use of a food matrix as a taste carrier will improve the ecological validity aspect of the study.

The use of real food samples, however, must be considered due to the possibility of cross-modalities. Cross-modal interactions between sensory cues occur among taste, aroma, texture, colour, shape and sound (Bult, de Wijk, & Hummel, 2007; Wang et al., 2019). In assessing intensity and hedonic perceptions using real food samples, children could be distracted by the effect of aroma and texture, which may change due to various tastant concentrations. For example, in the case of grapefruit juice, sucrose addition not only changed the taste intensity for sweetness, bitterness and sourness but could also modify the texture and possibly alter the aroma. The juice becomes thicker as sucrose addition is increased, and the sweetness aroma becomes stronger and could significantly affect intensity perceptions and acceptance due to these cross-modal interactions (Bult et al., 2007; Spence, 2011). Samant, Chapko, and Seo (2017) suggest using a single tastant in water solution because it can minimise cross-modal interaction and product information effect, ensuring objectivity in measuring sensory taste sensitivity. Water solutions, however, do not represent real food; thus, they lack ecological validity, especially when the objective is to address preferences towards foods. According to Hayes and Johnson (2017) simplifying a model food system into a simple aqueous solution generally absent in the eating context and is less ecologically valid than using food, thus may influence the experimental conditions.

Furthermore, sensitivity and hedonic responses to fattiness were measured using milk samples. The result might be different if other food matrices were employed because the perception of fat is highly dependent on the type of emulsion and fatty acid in the food matrix. However, there is no standard for the type of fatty acids or food matrices that should be used to measure sensitivity to fat. Moreover, fat content between different food matrices varies significantly (e.g., milk, cheese, butter, cream cheese). Therefore, we suggest that a future study should select a standard measurement for fattiness perception that could be applied in preadolescent subjects.

5.8.3. Implementing remote sensory testing during the Covid-19 pandemic

The remote sensory test had to be implemented due to the pandemic situation of Covid-19 (study 3). Conducting remote sensory testing was quite challenging, as the test had to be presented in a simple way with clear instructions to guide children remotely and keep their motivation during the entire test. The use of remote video instruction in sensory testing was reported to have been successfully applied to evaluate coffee products using adult panellists (Gonzalez Viejo, Zhang, Khamly, Xing, & Fuentes, 2021), and a similar remote method also worked very well in our data collection using preadolescent subjects.

In general, preadolescent children in Norway have developed digital literacy since they are introduced to the use of devices (tablets or laptops) at an early age. It is quite common for Norwegian preadolescents to use their laptops or tablets as learning devices, so they are familiar with an online setup. In addition, the school facilities in Norway support the application of remote testing since they are usually equipped with facilities such as wi-fi, smartboards or smart screens and speakers, including a laptop or tablet for each child. These conditions make it even more feasible to conduct remote testing at schools. The same method, however, may not be possible to implement in other countries due to the gaps in facilities at schools or the digital literacy levels of children. In addition, to the current date, there have been no reported studies about the validation of remote sensory tests in preadolescents. We suggest validating this method as one of the alternative data-collection approaches for future studies.

5.8.4. Study limitations

Our study had some limitations. First, there were limited data from the children's parents regarding CEBQ and FPQ (69 complete responses from a total of 106 parents (66%)), which suggests the need for larger numbers of participants in future research to confirm the results obtained from this study. Second, the children's BMI was not quantified by anthropometry measurements but calculated based on self-reported weight and height from their parents. This was considered inaccurate since parents may overestimate or underestimate their child's weight or height. Third, the group sizes between the normal-weight and overweight/obese children were not balanced (n=47 (70%) normal weight and n=22 (30%) overweight/obese) and may be problematic in statistical analysis and this could influence the results. It was difficult to find overweight/obese children, however, as we did not specifically recruit children with high BMI at the schools. Involving hospitals or healthcare centres that treat childhood obesity is suggested for future studies as a way to recruit obese and/or overweight subjects to achieve a balanced number among the BMI groups. Fourth, in study 2, the children had to evaluate different water-solution samples to measure their taste sensitivities (42 samples in total) right before they evaluated the milk samples. This practice was conducted without a break and might have initiated fatigue. This could lead to an insecure classification of children into their fattiness-sensitivity groups (fat sensitive vs not sensitive), as more children may fall into the non-sensitive group and no repetition in fattiness sensitivity measurement was conducted. Lastly, in the remote testing setup, we could not control the children's peer influence and noises during the test. All noises and interactions across children, however, were minimised as much as possible with the help of the teacher. Teacher involvement is particularly important in a remote testing set-up. Some teachers were very engaged in the test activities, and some were not, which significantly influenced the classroom set-up, despite the standard setting that had been implemented at school (e.g., wi-fi, a laptop or tablet per child, smart screen, camera, speaker). These conditions, therefore, might have influenced the quality of our data collection in the remote testing.

6. Conclusion and Future Perspectives

In conclusion, this study suggests that preadolescent children had different sensitivity perceptions across different basic tastes and that these individual differences influenced their liking. A significant effect was seen in the model food of grapefruit juice; liking was significantly influenced by responsiveness to sweetness, sourness and bitterness. A significant relationship was also found in fattiness sensitivity, indicating that children who were less sensitive to fattiness tend to like high-fat milk and have a higher liking of selected fatty foods compared to children with high fattiness sensitivity. No significant effect was found in vegetable broth, suggesting that the relationship between taste sensitivity and hedonic responses may depend on the type of sample used. The use of vegetable broth as a taste carrier may not be recommended in terms of ecological validity due to context issues, suggesting the need to select other food matrices that are more relevant to representing saltiness and umami for future studies.

This study demonstrates that preadolescents are able to distinguish different basic taste modalities and show prominent preferences for sweetness and avoidance to bitterness and sourness. This study also indicates the associations between taste sensitivity and eating behaviour, in particular for food responsiveness, emotional overeating and desire to drink. This result could be used as a preliminary finding, and we suggest involving a larger number of participants in future studies to confirm this association.

The common taste-sensitivity measurements evaluated by preadolescent subjects were shown to be correlated one to another with weak correlation effects. This indicates that each approach measures different aspects of taste-sensitivity perception and could not be substituted for any other. Moreover, the use of different approaches to measuring taste sensitivity and liking responses in preadolescents will generate different results. Method selection should be considered, with a suggestion of using suprathreshold measurement to study taste perception in relation to food preferences.

Furthermore, individual differences in bitterness perceptions towards different bitter compounds were also observed. Children have different perceptions of bitter taste intensity and liking of quinine and caffeine. This highlights a consideration in the selection of which bitter compound to use to study bitterness sensitivity since different bitter tastants could elicit different bitterness perceptions. Taste sensitivity did not influence food propensity, food choice, familiarity or neophobia. This indicates that there are no systematic relationships between taste sensitivity and these variables and may suggest the involvement of other extrinsic factors than taste sensitivity.

This study also provides an insight regarding the importance of assessing taste perceptions using actual food samples or water solutions. The model foods representing a real food matrix are more relevant in terms of the food context in which to measure both taste sensitivity and hedonic responses. There is, however, a consideration when applying real model food samples due to the possibility of cross-modality interaction. The different taste carrier options should be taken into consideration in future studies, and the selection will depend on the study objective. Moreover, the selection of an appropriate fatty acid and food matrix to measure fattiness sensitivity in preadolescents is suggested for future studies, because fattiness perceptions are highly dependent on the type of fatty acid and food-matrix emulsion used.

It is important to build a comprehensive understanding regarding the relationships between taste sensitivity and food preferences in preadolescents. The knowledge gained from this study could support the development of efficient strategies to promote healthy eating in this age group by considering individual differences towards taste stimuli. For example, to improve the acceptability of food that has generally low acceptance, such as vegetables, we should consider preadolescents' taste sensitivity because different taste perceptions may result in different acceptance. Our study confirms that individual differences in taste-sensitivity perception could significantly affect liking and possibly influence eating behaviour in preadolescent children.

More research is called for to ascertain whether the relationships between taste sensitivity and food liking follow the same pattern in a cross-cultural study. In addition, we suggest that other factors, such as children's personality traits, peers, cultural and environmental factors and other extrinsic factors could be further investigated, as these factors could influence taste sensitivity and may directly affect food liking in preadolescent children.

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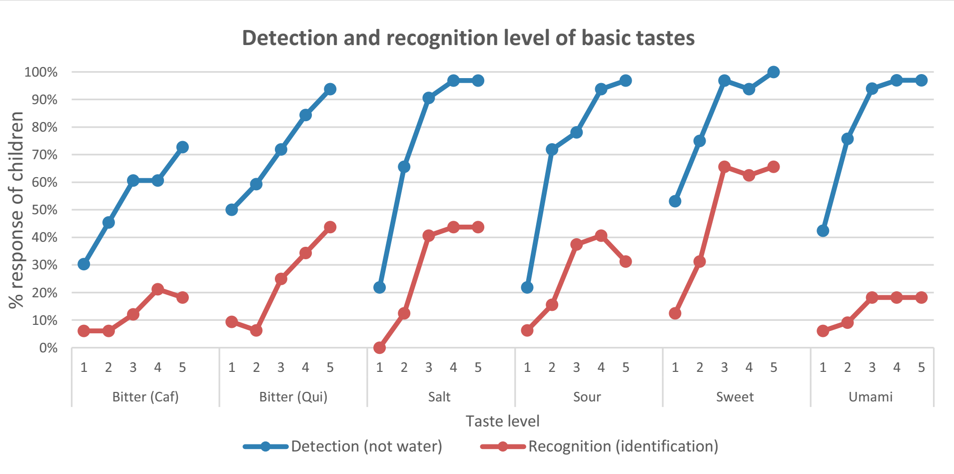
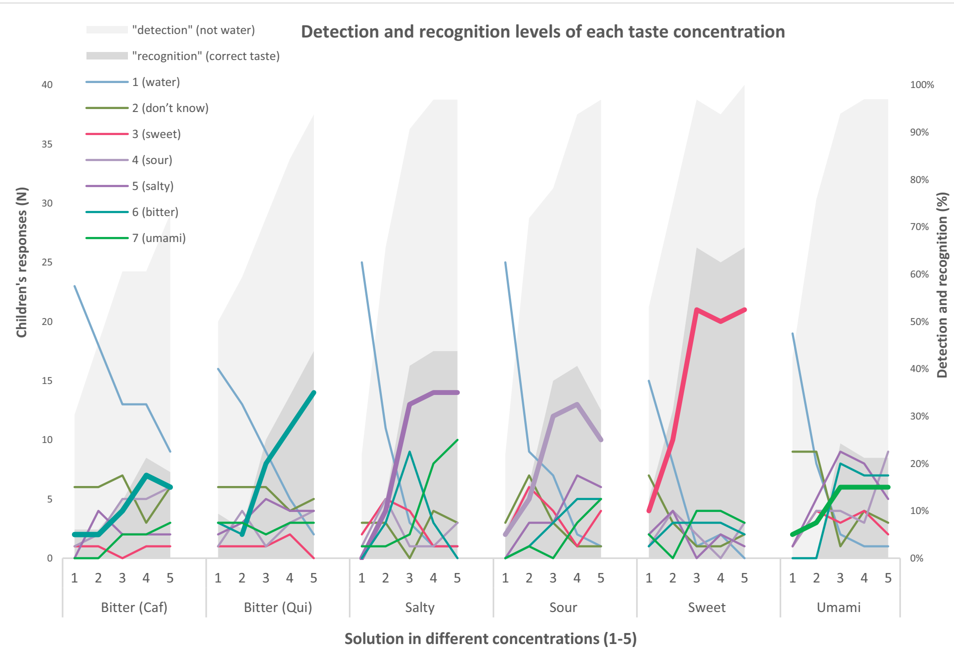
Appendix

The detection and recognition level for each basic tastes per concentration level based on pilot-test of study 2 with 42 children aged 12-13-years.



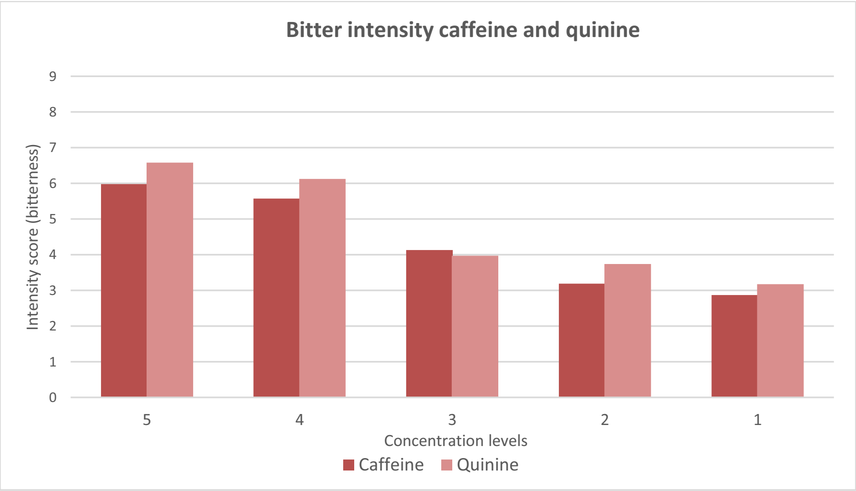


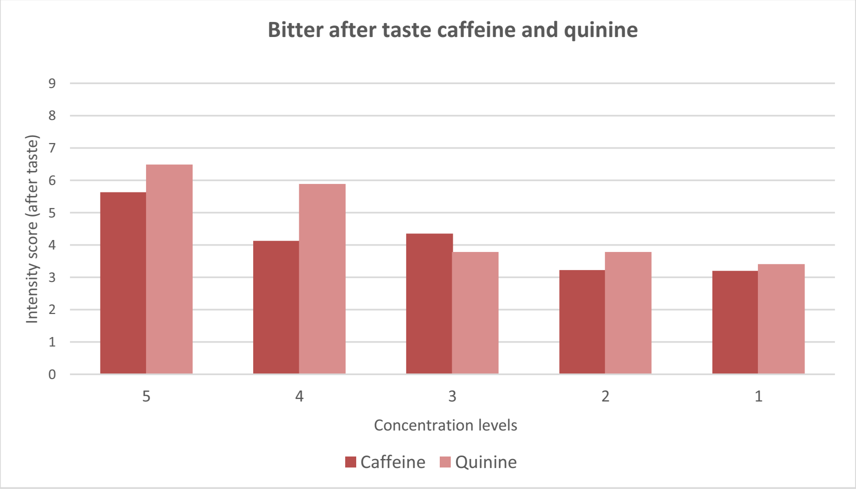
Bitterness intensity level and after taste of caffeine and quinine

Evaluation using QDA by trained panelist (n=9)

Concentration Levels	Bitter taste intensity		After taste (10 seconds)	
	Caffeine	Quinine	Caffeine	Quinine
5	6.0	6.6	5.6	6.5
4	5.6	6.1	4.1	5.9
3	4.1	4.0	4.4	3.8
2	3.2	3.7	3.2	3.8
1	2.9	3.2	3.2	3.4

No significant differences between bitterness intensity between caffeine and quinine for each concentration based on evaluation by the trained panel (n=9). However, quinine have a longer and intense bitter after taste compared to caffeine in level 4.

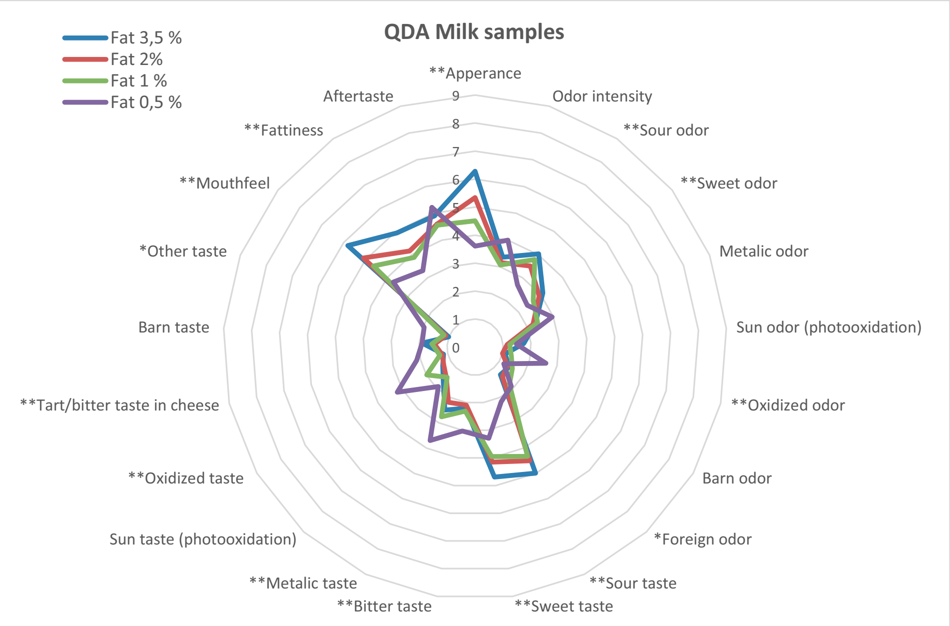




QDA of milk samples

Attributes	Fat 3.5 %	Fat 2%	Fat 1 %	Fat 0.5 %
Appearance	6.28^{a}	5.34^{b}	4.51^{b}	3.61^{c}
Odor intensity	3.36^{a}	3.16^{a}	3.07^{a}	4.0^{a}
Sour odor	4.03^{a}	3.51^{ab}	3.79^{b}	2.69^{c}
Sweet odor	3.10^{a}	2.93^{ab}	2.66^{ab}	2.39^{b}
Metallic odor	2.31^{a}	2.22^{a}	2.40^{a}	2.96^{a}
Sun odor (photooxidation)	1.74^{a}	1.50^{a}	1.24^{a}	1.48^{a}
Oxidized odor	1.10^{b}	1.01^{b}	1.33^{b}	2.60^{a}
Barn odor	1.41^{a}	1.33^{a}	1.54^{a}	1.19^{a}
Foreign odor	1.34^{ab}	1.44^{a}	1.81^{a}	1.91^{a}
Sour taste	4.99^{a}	4.50^{a}	4.33^{a}	2.16^{b}
Sweet taste	4.69^{a}	4.15^{a}	3.95^{ab}	3.29^{b}
Bitter taste	2.21^{b}	2.09^{b}	2.31^{b}	3.03^{a}
Metallic taste	2.49^{b}	2.19^{b}	2.76^{b}	3.70^{a}
Sun taste	1.66^{a}	1.50^{a}	1.46^{a}	1.92^{a}
Oxidized taste	1.33^{b}	1.29^{b}	1.99^{b}	3.21^{a}
Tart/bitter taste in cheese	1.15^{b}	1.20^{b}	1.29^{b}	2.14^{a}
Barn taste	1.90^{a}	1.45^{a}	1.54^{a}	1.90^{a}
Other taste	1.01^{b}	1.12^{b}	1.19^{b}	1.95^{a}
Mouthfeel	5.81^{a}	5.1^{ab}	4.64^{b}	3.73^{c}
Fattiness	4.94^{a}	4.15^{ab}	3.87^{b}	3.30^{b}
Aftertaste	4.91^{a}	4.60^{a}	4.56^{a}	5.22^{a}

Note: different letters across columns indicate significant differences between means values based on Tukey's HSD test ($p>0.05$)



Note: ** indicating significant differences between mean values based on Tukey's HSD test

Example of consent form to parents and children (for study 2) in Norwegian

Vennligst les med barnet og returner til kontaktlærer med både din og barnets underskrift.

Vil du bli Smaksdetektiv?

Hei, du er herved invitert til smaksdetektivspillet!
I dette spillet vil du oppleve grunnsmakene søtt, surt, bittert, salt og umami, og du skal smake deg fram til den feteste melkeprøven. Du får også smake på en papirstrimmel – smaker den bitter for deg? Gjennom disse aktivitetene kan du finne ut hvor følsom du er for bestemte smaker.
Alt skal besvares hver for seg på nettbrett eller PC. Aktivitetene vil finne sted i uke 43, i undervisningstiden og i samarbeid med 6. trinns lærere. Velkommen som smaksdetektiv!

Oppgavene

1. **Smaksdetektiv**: Her får du servert flere prøver med vann med forskjellig smak og styrke. Din oppgave er å identifisere hvilke kopper som smaker noe annet enn vann og hva de smaker.
2. **Liker du …?** Underveis i smaksdetektivoppgaven vil du besvare hvor godt du liker ulike matvarer.
3. **Hvilken melkeprøve har mest fett?** I denne testen vil du få servert to og to melkeprøver. For hvert par er oppgaven å identifisere hvilken av de to prøvene du mener har mest fettsmak og hvilken du liker best.
   Er du enig i …? Hvis du har melkeallergi, skal du løse en alternativ oppgave der du skal si om du er enig eller uenig i ulike påstander om mat.
4. **Teststrimmel:** Du skal smake på en papirstrimmel og si hvor sterkt du kjenner bittersmaken.
5. **Spørreskjema for foresatte:** Denne oppgaven er det foresatte som skal kose seg med hjemme, der de skal besvare noen spørsmål om dine matvaner og preferanser. Din oppgave er bare å sjekke om en voksen har besvart skjemaet!

Hvorfor kjører vi denne aktiviteten?

Vi er smaksforskere fra Nofima som studerer smakssansens rolle i etableringen av matvaner hos barn. Denne forskningen er en del av et større internasjonalt prosjekt. For mer informasjon besøk www.edulia.eu.

Deltakelsesregler

- I tråd med reglene ved Norsk Senter for Forskningsdata (NSD), **må du returnere skjemaet underskrevet av deg og en foresatt for å kunne delta**. Ingen skjema, ingen spill!
- Hold deg rolig og konsentrert i løpet av aktiviteten. Utfør testene for deg selv; **ikke kopier klassekamerater**, bare **du** vet hvordan ting smaker i din egen munn.
- Deltakelse er **frivillig**. Det vil si at du kan fritt avbryte eller trekke deg fra spillet til enhver tid uten konsekvenser.

Hvis du har spørsmål om aktivitetene, vennligst kontakt oss:

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The ability of 10–11-year-old children to identify basic tastes and their liking towards unfamiliar foods

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ABSTRACT

The involvement of children in sensory evaluation and consumer research continues to increase and has become crucial in the food industry, as children sensory perceptions differ from adults. Research on basic taste sensitivity in children provides contradictory results, with most of the studies not considering the familiarity aspect of the food samples. Familiarity can lead children to memories of the food which are able to influence their taste perception and liking. This study aims to investigate the ability of 10 to 11-year old children in identifying sweetness, saltiness, sourness, and bitterness in unfamiliar food samples. The taste identification data was collected from 98 children using 19 food samples representing the four basic tastes of sweet, sour, salty, and bitter. For each food sample, the children evaluated their familiarity, the basic taste(s) they perceived using the check-all-that-apply (CATA) method and scored their liking. Their basic taste identification ability was investigated by comparing their results to trained panellists as a reference. The food samples were unfamiliar to most of the children (never tasted by 85% of the children on average). Correspondence Analysis (CA) showed that children were able to identify the basic tastes of sweet, sour, salty, and bitter in the unfamiliar foods, with a high congruency to the trained panellists. However, children's identification ability was lower when combinations of dominant basic tastes occurred. Principal Component Analysis (PCA) demonstrated a positive correlation between the presence of sweet taste and the children's liking while sour and bitter tastes showed the opposite.

1. Introduction

Children have become one of the largest market segments for major brands and corporations. The purchasing influence of children under the age of 15 in the USA market is estimated to be more than $300 billion with 60% of this market represented by the foods and beverages sector (Popper & Kroll, 2011). This has resulted in the increasing involvement of children in sensory and consumer research. They participate not only in projects related to product development, but also in studies relating sensory aspects to healthy eating and behaviour (Laureati, Pagliarini, Toschi, & Monteleone, 2015). Performing sensory testing with children is important, but also challenging because they have immature physiological and cognitive abilities (Jilani, Peplies, & Buchecker, 2019). Oram and colleagues (2001) investigated children's chemosensory skills and reported that 8–9 year old children have limited perceptual-attentional skills to analyse the complex stimuli of the combination of basic tastes in sensory testing. Therefore, sensory testing with children should use different methods compared to testing with adults (Popper & Kroll, 2011; Laureati et al., 2015). A rapid sensory method in children such as Check-All-That-Apply (CATA) was suggested by Laureati and Pagliarini (2018) due to its simplicity. Moreover, children have different perception patterns of tastes (Drewnowski, Mennella, Johnson, & Bellisle, 2012) and preferences towards foods compared to adults (Forestell & Mennella, 2015). Children aged 5–10 years old reported to prefer salty taste in broth (Julie A Mennella, Finkbeiner, Lipchock, Hwang, & Reed, 2014), and they preferred a higher level of sweetness in lemonade beverages (Zandstra & de Graaf, 1998) than adults. In addition, children's gustatory and olfactory abilities to investigate food are still questionable, particularly in terms of their taste acuity (Oram, Laing, Freeman, & Hutchinson, 2001; Wendin, Prim, & Magnusson, 2017) and reliability (Visser, Kroeze, Kamps, & Bijleveld, 2000).

Children's taste perception ability begins to develop during the gestation period (Bradley & Stern, 1967; Mistretta and Bradley, 1975) with the exposure of nutrients and tastes from the mother's diet via the amniotic fluid (Mennella, 2007). This implies that children have been

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exposed to different tastes and aroma stimuli even before they were born (Ventura & Worobey, 2013), thus triggering the development of their taste preferences before birth (Birch, 1999; Ganchrow & Mennella, 2003). Taste perception and preferences will further develop as infants are exposed to different tastes and flavours through their mother's milk (Schwartz et al., 2017). A study by Forestell and Mennella (2017), suggested that infants are able to differentiate between the basic taste stimuli of sweet, sour, bitter and umami.

Studies investigating children's basic tastes perception provided contradictory outcomes. A study conducted by Laing et al. (2008) involving seven-year-old children reported that they had good ability to identify four basic tastes and food odorants. With regard to saltiness, some research indicated that children aged 6–12 year old have poor taste perception (Baker, Didcock, Kemm, & Patrick, 1983; Zandstra & de Graaf, 1998; Guinard, 2000) while other studies reported that they have higher taste sensitivity and preferences for salty taste compared to adults (Baker et al., 1983; Beauchamp & Cowart, 1990). On the contrary, Liem (2017) concluded that there was no strong evidence regarding the differences of saltiness sensitivity level between children and adults suggesting that they have a similar perception to the intensity of salty taste. However, Beauchamp and Cowart (1990) report that 5–10 year old children preferred higher concentrations of salt in broth and this result positively correlated with the intake of salty foods in their daily diet but not with their sensitivity to saltiness.

In addition, adolescent children showed a stronger correlation between sodium intake and the perceived intensity of salty taste compared to adults (Quader et al., 2017). Similar results were also obtained for sweetness in 5–10 year old (Mennella, Pepino, & Reed, 2005), 4–6 year old (Vennerød, Nicklaus, Lien, & Almli, 2018) and one-year-old children (Drewnowski et al., 2012). Further, a study from Liem, Mars, and de Graaf (2004) suggests that children as young as five years old showed good consistency in discriminating different sweetness levels in orangeade beverages.

With regard to bitterness, children aged 5–10 years old have been reported to have individual preferences according to their genetic determinants (Mennella et al., 2005) and they have a higher perception for bitter taste than adults (Mennella, Spector, Reed, & Coldwell, 2013). This affects children's food intake of fruit and vegetables (Bell & Tepper, 2006), food preferences (Negri et al., 2012), and food neophobia (Laureati, Bertoli, et al., 2015).

With regard to sourness, there has been inconclusive research investigating children's ability to identify sour taste (Liem & de Graaf, 2004). Vennerød, Hersleth, Nicklaus, and Almli (2017) conducted a taste sensitivity study in 4-year-old children, using equivalent concentration levels of the ISO 3972 standard across basic tastes. These authors observed better taste detection ability for sourness than for the other basic tastes, suggesting the need to decrease the sourness intensity of reference concentrations in the ISO standard. Furthermore, sour taste was not investigated in the other taste sensitivity studies involving 3–10 year old children (Knof et al., 2011; Lanfer et al., 2013). As for umami, age was reported to have a significant effect in perceiving umami taste, indicating that 13-year-old children have a lower sensitivity for this taste than 16–18 year-old adolescents (Overberg, Hummel, Krude, & Wiegand, 2012).

The taste perception ability in 9–11-year old children was previously assessed in a descriptive sensory evaluation test using chocolate products (Sune, Lacroix, & Huondekermadec, 2002). The results showed that the children had good capability in performing a descriptive test, in line with trained panellists. Nevertheless, the same study also revealed that the children had difficulty in describing complex sensory properties such as texture and mouthfeel as was also reported by Oram et al. (2001), suggesting a real semantic gap between children and trained panellists (Sune et al., 2002). Furthermore, as for adults, individual variation between children exists in sensory sensitivity towards different taste stimuli (Blissett & Fogel, 2013).

Most of the research investigating taste sensitivity in children have used aqueous taste solutions (Oram et al., 2001; Knof et al., 2011; Lanfer et al., 2012; Hartvig, Hausner, Wendin, & Bredie, 2014) or model food as the samples. The model foods that have been used in taste sensitivity studies are beverages (Liem & de Graaf, 2004; Vennerød et al., 2018), broth (Beauchamp & Cowart, 1990), or crackers (Lanfer et al., 2013; Mennella et al., 2014) that varied in the concentration level of the target tastes. When familiar food items are used in testing, the familiarity of the food could lead children to associate them with certain taste memories that might affect their taste perception (Laureati & Pagliarini, 2018). This stimulus context of the familiar food may also influence acceptance of the selected target tastes (James, Laing, Oram, & Hutchinson, 1999). As reported by Popper and Kroll (2011), children have the capability to memorize the enjoyment of food both in its taste and experience. Due to the increase in children's involvement in sensory evaluation studies there is a need to study children's ability to perceive and identify taste in complex stimuli. To our knowledge, no previous study has investigated preadolescent's ability to identify basic taste stimuli when the familiarity aspect of the food is taken away. In addition, complex food items were used in this study instead of designed model foods, ensuring more relevance for industry applications.

The objective of this study was to investigate the taste identification ability of 10 to 11-year old children in unfamiliar food samples, as well as their liking for unfamiliar foods representing different basic tastes. This age group was chosen because children this age are not highly neophobic (Dovey, Staples, Gibson, & Halford, 2008) and are able to perform self-administered tests with limited assistance from the experimenters (Popper & Kroll, 2011). Based upon previous research, we expect that children are better able to identify sweet taste than other basic tastes. Moreover, we expect that the combination of basic tastes that naturally exist in food will decrease children's taste identification ability.

2. Method

2.1. Participants

One hundred and five children aged between 10 and 11 years old from two local schools in the Follo region, Akershus district, Norway were invited to the study in late 2013. The ages of the children were not recorded, however, all the children were born in the same calendar year and attended the 5th grade of elementary school. In total, 98 children participated in this study, wherein 53% of the participants were boys and 47% were girls. Both the parents and their children were provided with information about the research objectives and activities in the form of a flyer, and parents had to fill out information addressing any dietary restrictions (i.e. due to religion, beliefs or personal health) of their children. Children who participated in this experiment gave their verbal consent in addition to the signed written consent from their parents. The children in one of the schools were also part of a food exposure intervention study that is controlled for in the data analysis of this study, but not reported in this paper (Nilsen, 2014). The children of the other school were only enrolled in the food tests reported here. The ethical clearance has been approved and all recruitment and data protection processes are in line with the regulation from The Norwegian Centre for Research Data (NSD) and refer to the Declaration of Helsinki.

2.2. Food samples

Nineteen food samples from five categories of dairy, meat based, cereals, fruit and vegetables, and sweets were tested by the children (Table 1). The unfamiliarity aspects of the food were taken into consideration in preselecting the food samples, meaning the selected items are not commonly served in the Norwegian diet, particularly for children, but are available in Norway (i.e. all the food samples were bought in Norway) and not known for triggering reactions of disgust (e.g., we

Table 1
Food samples.

Food Group	Food Samples	Week[1]	Dominant Taste	Evaluated[2] (n)	Unfamiliarity[3]		Actual tasting[4]	
					n	(%)	n	(%)
Dairy	Goat cheese	W1	Sour	92	86	93.5	88	95.6
	Fermented milk	W13	Sour, bitter	86	64	74.4	78	90.7
Meat based	Cocktail salami	W1	Salt	84	76	90.5	81	96.4
	Chorizo	W5	Salt, sweet	87	74	85.1	84	96.6
	Beef jerky	W13	Salt, sweet	89	79	88.8	84	94.4
	Crab stick	W13	Salt, sweet	90	73	81.1	80	88.9
Cereals	Durum wheat semolina	W1	Sweet	92	60	65.2	92	100.0
	Bulgur	W13	Sweet	90	83	92.2	89	98.9
Fruit and vegetables	Cucumber pickle	W1	Sour	94	74	78.7	84	89.4
	Grapefruit	W1	Sour, bitter	93	79	84.9	90	96.8
	Persimmon	W1	Sweet	93	75	80.6	91	97.8
	Artichoke heart	W5	Sour, salt	92	90	97.8	85	92.4
	Goji berry	W5	Bitter	87	80	92.0	85	97.7
	Kumquat	W5	Sour, bitter	90	84	94.4	86	95.6
	Water chestnut	W5	Bitter	92	73	79.4	88	95.6
	Carrot juice	W13	Sweet	89	76	85.4	89	100.0
Sweets	Coconut cubes	W5	Sweet	87	79	90.8	85	97.7
	Root beer	W5	Sweet	91	60	65.9	88	96.7
	Ginger candy	W13	Sweet	89	84	94.4	85	95.5
Mean ± SD				90 ± 3	76 ± 8	84.9	86 ± 4	95.6

[1] week of the food being evaluated.
[2] children who had joined the evaluation.
[3] children who had never tasted the food before the evaluation.
[4] children who chose to taste the food during evaluation.

did not serve snails, very smelly cheeses, etc.). The list of unfamiliar foods was developed by the research team and colleagues based on our experience and cultural knowledge. We validated our sample selection by collecting children's (un)familiarity response to the foods during the test. Moreover, the food samples also needed to reflect the four basic tastes of sweet, sour, salty, and bitter (umami was not included as a target taste as the pretesting indicated that this word was often unfamiliar to children in this age group). A preliminary study was thus conducted in order to select representative food samples based on their dominant taste(s), with dominant taste being defined as the most striking taste perception (Pineau et al., 2009). Seven well-trained sensory panellists were involved to test a total of 46 candidates of unfamiliar food samples. Working in pairs, the panellists determined by consensus one or two dominant basic taste sensations present in each sample. Principal Component Analysis (PCA) was used to map the samples according to its basic taste (PCA bi-plot available in Supplementary materials, Fig. S1). A subset of foods that showed distinct dominant basic taste(s) and were representative of the five food categories (Tugault-Lafleur & Black, 2019) were selected for testing with the children. In the selection process, foods that would be difficult to serve at school due to a long preparation time were not retained.

From the preliminary study, thirty-six unfamiliar food samples were selected in total, among which 15 food samples were used in the food exposure intervention study (Nilsen, 2014) and an additional two represented the umami taste; results from these 17 food samples are not reported here. The present paper reports on 19 unfamiliar food samples tested on the children to investigate their ability to identify sweet, sour, salty and bitter tastes. All the food samples were prepared in the sensory laboratory at Nofima in Aas, Norway and transported to the school on the same day of the evaluation. The food samples were prepared and served in a ready-to-eat form, which meant they were washed, peeled and cut into one bite portion sizes. Durum wheat semolina and bulgur were cooked in water. For practicality and safety reasons, all food samples were served and evaluated at room temperature.

2.3. Test procedure

All the tests were organized and conducted in the children's respective classrooms. A school environment was chosen instead of a laboratory setting because it is important to create a friendly atmosphere for the children (Mennella & Beauchamp, 2008; Jilani et al., 2019). We expected this to encourage them to join the evaluation to taste the unfamiliar food. All the children evaluated the 19 unfamiliar food samples over three sessions conducted in week one (6 items), week five (7 items) and week thirteen (6 items) (Table 1). In the first session (week 1), at the beginning of the test, children were asked to perform a sorting task consisting of 72 food item images in the form of cards. These included different food types (e.g. meat, vegetal and dairy products), as well as variations within a food category (e.g. red and black tomatoes, boiled and fried eggs, grated and cooked carrots). They were asked to sort the cards into two categories of "I have tasted" or "I have never tasted" this food before. The percentage of the tasted food items were recorded as the food variety background (FVB). In order to keep the unfamiliarity aspect during the evaluation, none of the test foods were presented in the sorting task.

In each session, the children were served a set of 6 or 7 unfamiliar food samples on individual trays. The samples were served all at a time, in randomized balanced order within, but not across sessions. The children's responses were recorded in a paper questionnaire. For each food sample, the children first reported their familiarity by choosing from the following options: "I have never seen this food before", "I have seen this food before, but have never tasted it", and "I have tasted this food before" adapted from Aldridge, Dovey, and Halford (2009) and their expected liking was recorded on a seven-point pictorial hedonic scale and measured just before they tasted the food samples. Afterwards, the children were invited to eat the food sample. They could freely eat the whole serving, taste only partially or decline tasting. This was reported on the questionnaire, which offered all three options to make sure the children fully understood that any of these behaviours was accepted. Spitting out could occur but was not reported on the questionnaire. The allergenicity of each sample was always announced (i.e. contains milk, gluten, etc.) before the evaluation to secure that only safe foods were served to each child.

During tasting, the children indicated their response towards their liking on a seven-point pictorial hedonic scale (Popper & Kroll, 2011; Kroll, 1990) and their willingness to taste this food again in the future

(7-point pictorial scale anchored with "NO!!" to the left, "Maybe" in the middle and "YES!!" to the right). The expected liking and the willingness to try the food again in the future are not reported in this paper. Additionally, the children indicated the dominant basic taste sensations that they perceived in a Check-all-that-apply (CATA) question offering four alternatives of sweet, sour, salty and bitter. In addition, children completed the Food Situations Questionnaire (FSQ) from Loewen and Pliner (2000) adapted to the Norwegian culture (e.g. lunch pack for a walk in the forest instead of picnic) to measure food neophobia. The FSQ was distributed to the children in week one and week five to measure the potential effect of the food exposure intervention study conducted in one of the schools. In the present study, it is important to verify that all children had stable FSQ scores at week one and week five to establish that there would be no effect from the food intervention study on the taste identification testing.

The children finished one session of food tasting in about 15 min and during the test they were provided enough break in between the food samples to rinse their mouth with water. All children tasted the same set of food samples in each session. The food samples were served in a 50 ml disposable plastic plate and introduced to the children in a one-bite portion size. The children received the food samples on a tray with rinsing water, plastic spoon, napkins, and a spitting cup along with the questionnaire. For each food sample, the front page of the questionnaire showcased a photo, the name of the food sample, and a short of non-taste-related sensory and non-hedonic information (Fig. 1). This information was provided aiming to break the barrier of the unfamiliar food sample (Mustonen, Rantanen, & Tuorila, 2009) and make it less intimidating to taste the samples (Dazeley & Houston-Price, 2015). During the evaluation, the children were asked to taste the food individually, quietly, and not to talk to one another.

2.4. Data analysis

To assist food sample selection among the original 36 candidate samples, a PCA was conducted on the taste identification response from the trained panel (bi-plots available in Supplementary material, Fig. S1). The FVB and FSQ scores between the two schools were compared using student t-tests to verify that they were similar and could be further analysed as one group. For each food sample, data from children who did not taste it were excluded from the analysis. The children's and trained panellists' taste identifications for each food were recorded as binary data. We conducted two different analyses to investigate the ability of children to identify basic tastes, first Correspondence Analysis (CA), then we developed and calculated a taste identification ability score. CA was performed on the contingency table of children's data with food samples as rows and basic tastes as columns, while taste identifications from the trained panellists were involved as supplementary columns. Additionally, the similarity between the children and the trained panel's taste identification was investigated by computing the RV coefficient for factors 1 and 2 from the distinct correspondence analyses. The closer the RV coefficient is to one, the higher the similarity between the matrices (Næs, Brockhoff, & Oliver, 2010).

The taste identification ability score was calculated for each child using the trained panellists' identification data as a reference for each food sample. Children received a score of 1 for each correctly ticked taste, and a score of -1 for each incorrect or omitted taste. For example, grapefruit is dominated by bitter and sour taste. If the children ticked only sour and not bitter, they received a score of $+1$ for sour and -1 for bitter; if they ticked both tastes they received $+1$ for each taste, and if they ticked none of these tastes they received -1 for each taste. As there were 19 samples, the ability scores per taste ranged between -19 as the lowest and 19 as the highest. The average of the score per taste was also calculated and compared.

A mixed model Analysis of Variance (ANOVA) was used to investigate the effects of gender and taste identification ability on liking. In this model, children were included as random effect and the restricted maximum likelihood (REML) method was used for fitting the model. The Agglomerative Hierarchical Clustering (AHC) was applied on the taste identification ability score, and liking for the different clusters were then compared. This was aimed to see if clusters based on taste recognition also differed according to liking. The relationship between the basic tastes reference (from the trained panel) for each unfamiliar food sample and children's liking was analysed by applying Principal Component Analysis (PCA) with liking included as a supplementary variable. This analysis aims to explain how liking relates to the actual product tastes, in a preference mapping principle. The average liking score for each basic taste were also calculated. The significant difference tests were calculated at a 95% confidence interval level ($p < 0.05$) for the univariate analysis and Tukey's test was applied for pairwise comparisons. All data was analysed using XLSTAT Sensory (version 2019.1.1, Addinsoft, France).

3. Results

3.1. Food variety background for schoolchildren participating in the study

There was no significant difference between the two participating schools regarding the children's FVB (*P-value* = 0.25) indicating that the children from these two schools had similar food variety backgrounds before they started the experiment. The FSQ scores also showed no significant differences before (*P-value* = 0.48) and after (*P-value* = 0.44) the intervention study or at week one and week five,

Fig. 1. Examples of the short information (name, photo, and non-taste-related sensory and non-hedonic information of the food sample).

respectively. This means that the children from these two schools had similar neophobic backgrounds and no significant effect of the intervention study occurred in the school that participated in the food exposure study that could affect children's perception on this experiment. Further results will consider the full sample of children as one data set.

3.2. Unfamiliarity and actual tasting of the food samples

The self-reported (un)familiarity revealed that on average, more than 80% of the children had never tasted the food samples prior to this experiment, which means most of the food samples were unfamiliar to them (Table 1). Artichoke heart (97.8%), kumquat (94.4%), and ginger candy (94.4%) had the highest unfamiliarity, while durum wheat semolina (65.2%) and root beer (65.9%) were the most previously tasted food samples by the children. Further, the data show a very high tasting rate of the test foods during the experiment, with a range between 88.9 and 100% of the children tasting the food samples in this study. The least tasted sample was crab stick (tasted by 88.9% of the children) while the most tasted samples were carrot juice and durum wheat semolina (tasted by 100% of the children, Table 1).

3.3. Children's basic tastes response

Fig. 2 presents the children's responses for the dominant taste of sweet, sour, salty and/or bitter for each food sample. It can be seen from the results that sweet taste was perceived as dominant in persimmon (0.87), followed by coconut cubes (0.79), and ginger candy (0.61), while sour taste was perceived as the most dominant in cucumber pickle (0.70), followed by kumquat (0.67), and grapefruit (0.61). Salty taste was perceived as dominant in chorizo (0.70), followed by cocktail salami (0.60), and beef jerky (0.55), while root beer (0.51), goat cheese (0.48), and grapefruit (0.45) were dominantly perceived as bitter.

CA was performed to create a basic taste identification mapping of the unfamiliar food samples in children and the trained panel (Fig. 3). The children's response of basic tastes showed a similar pattern to what was obtained with the description from the trained panel for sweet, salty, sour and bitter only with a clearer product differentiation by the panel on Factor 2. The RV coefficient between the configuration (with two factors) from the children's data and the panel description was 0.92, (p-value < 0.001). The high RV coefficient indicates a high similarity between the children and the trained panel in performing basic taste identification for the whole sample set of the unfamiliar foods.

3.4. Children's basic taste identification ability

The children's basic taste identification ability scores were calculated using the trained panel's responses as a reference. The average correctness scores for each basic taste were calculated based on the food samples that represented those tastes. The sour taste (9.4 ± 4.1 SD) and the salty taste (9.5 ± 4.0 SD) showed to have a significant higher correctness score compared to the sweet taste (4.4 ± 3.9 SD) and the bitter taste (5.1 ± 4.3 SD) (Fig. 4).

The children's ability to identify basic taste was then further investigated by calculating the percentage of children who correctly identified the dominant taste of sweet, sour, salty and bitter in each food sample (Fig. 5). Fig. 5 has also presented the dominant taste per each food samples and has adjusted to the number of children who performed the actual tasting. The highest correct taste identification rates were obtained with persimmon (86.7% correct) and coconut cubes (78.6%) which both are characterized by sweet taste. The lowest taste identification rates were obtained for root beer (28.7%, sweet) and goat cheese (33.3%, sour). The results indicate that children tended to have a higher identification ability for sweet taste, particularly when sweet taste was present as dominant single taste in the unfamiliar food.

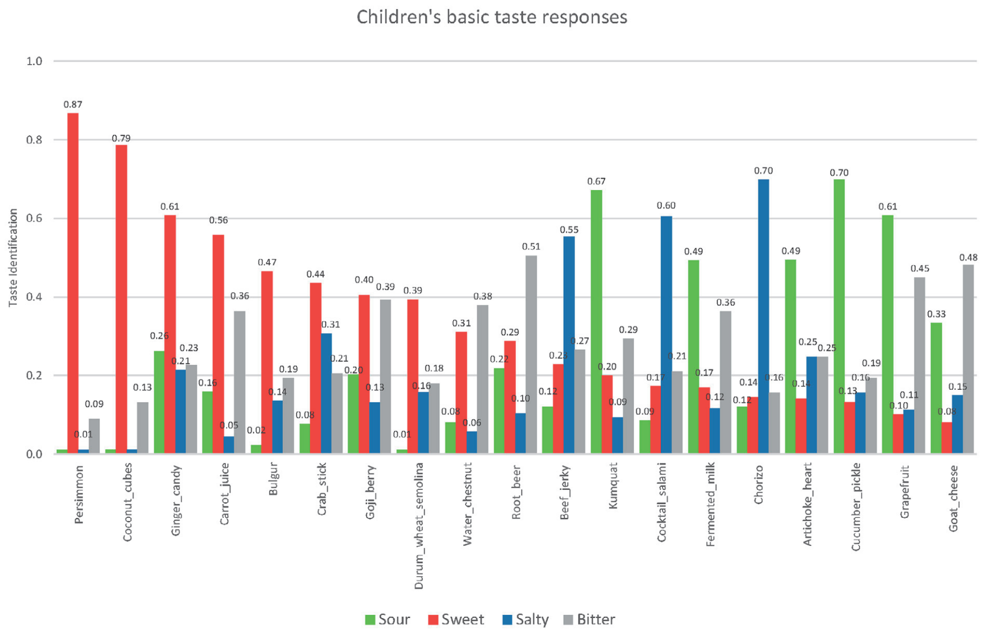

Fig. 2. Children's basic taste response per food sample, on average results (scale in binary 0–1, where 1, codes for dominance response of that taste).

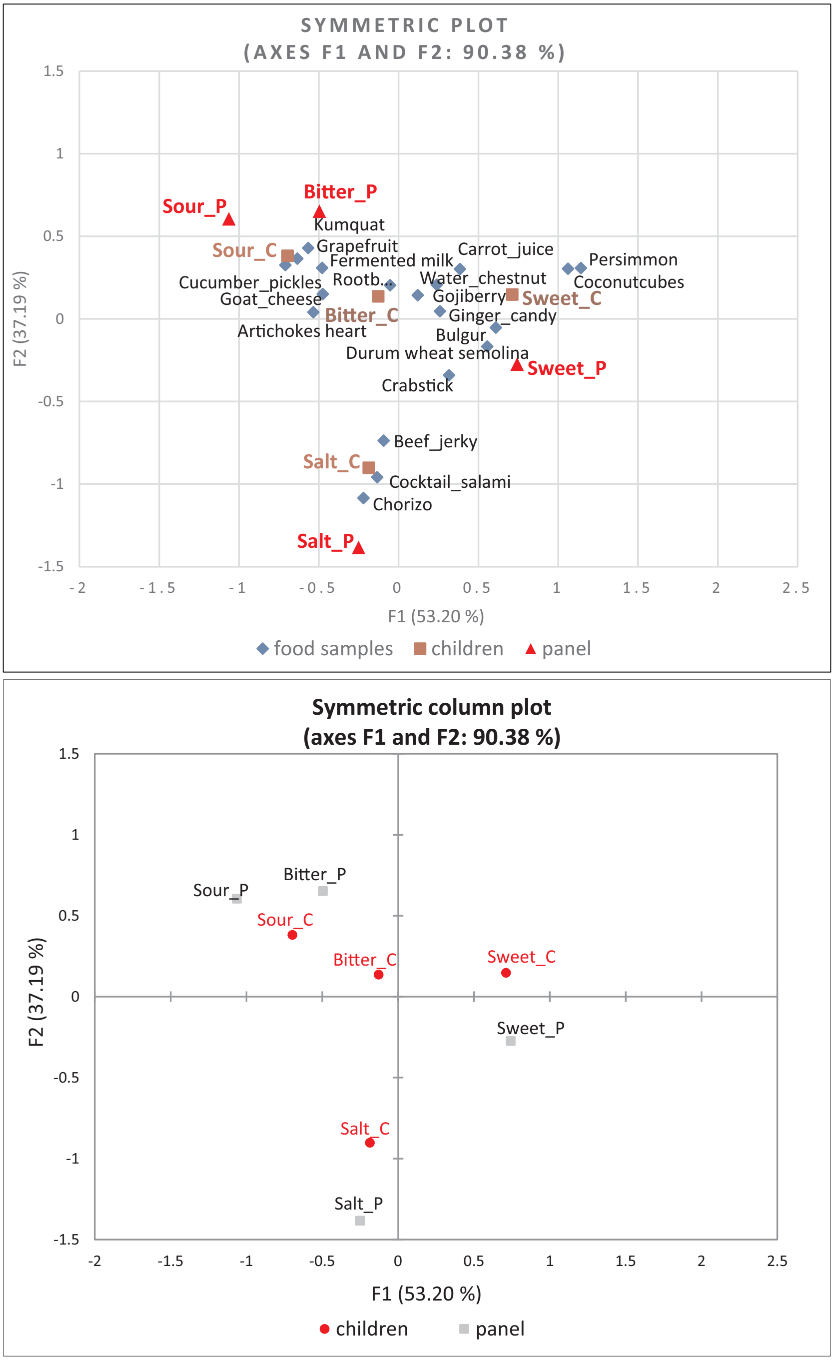

Fig. 3. Correspondence Analysis (CA) of taste identification between the children and the trained panel (P = panel, C = children).

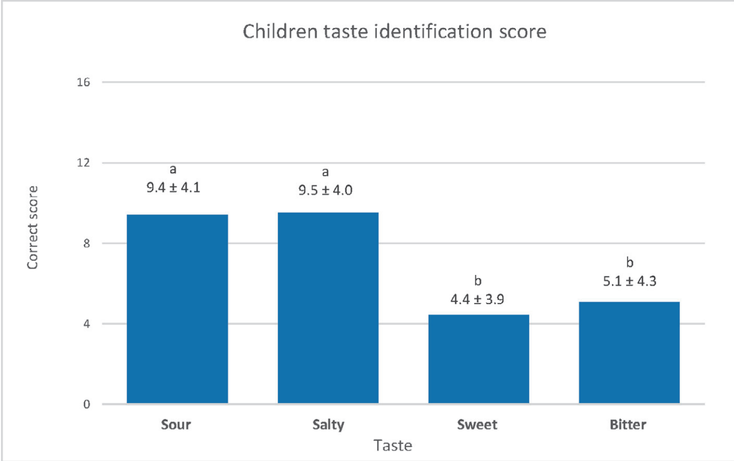

Fig. 4. Taste identification score. Different letters indicate significant differences in Tukey's pairwise comparison test ($p < 0.05$).

3.5. Children's liking

Fig. 6 presents the scatter plot of the basic taste identification of the children against liking for each food sample. Persimmon and coconut cubes were most often identified as sweet compared to other food samples and were most liked by the children. This is also supported by the results presented in Fig. 7 where the unfamiliar foods dominated by sweet taste were significantly the most liked (mean 4.9 ± 0.9 SD), while foods dominated by sour (mean 3.3 ± 1.2 SD) and bitter (mean 3.5 ± 1.3 SD) tastes were significantly least liked by the children.

The first two principal components of PCA analysis obtained from trained panel's response and children's liking explained 81.3% of the total variance (Fig. 8). The results showed a significant positive correlation to the liking for sweet taste (*Pearson* = 0.55, $p < 0.05$) and

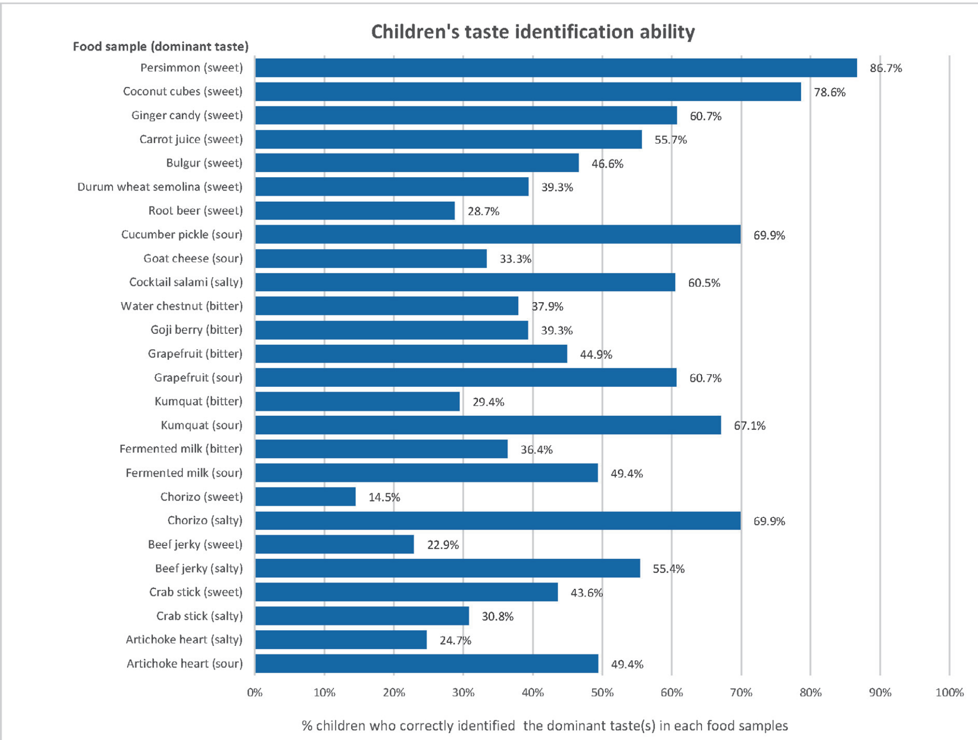

Fig. 5. Percentage of children who correctly identified basic taste(s) in each food samples.

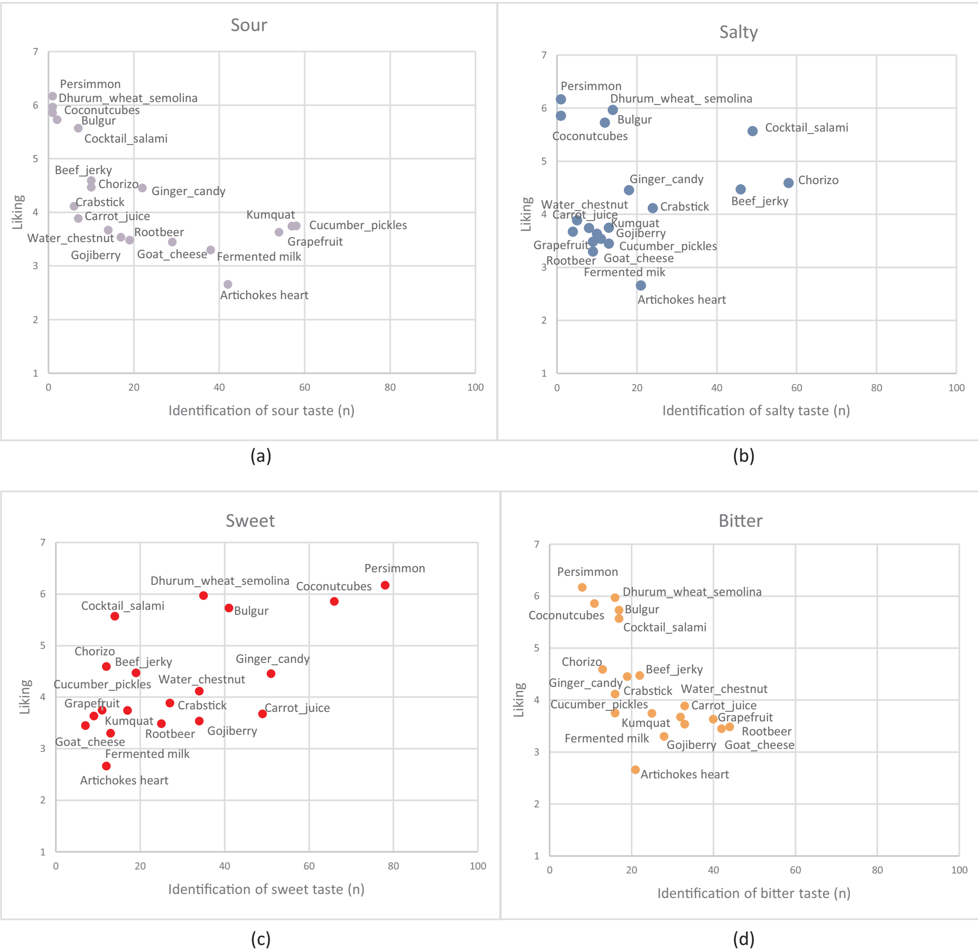

Fig. 6. The children's basic taste responses in relation to their liking of the food sample for sour (a), salty (b), sweet (c), and bitter (d) (n = number of children's responses).

significant negative correlation for sour taste (*Pearson* = -0.60, $p < 0.05$) and bitter taste (*Pearson* = -0.41, $p < 0.05$). Moreover, sweet taste also showed to have a strong negative correlation with sour (*Pearson* = -0.72, $p < 0.05$) and bitter (*Pearson* = -0.63, $p < 0.05$).

The exploration analysis conducted from the AHC method using children's taste identification score did not reveal any systematic patterns and correlations between the children's basic taste identification ability and their liking. This indicates that the children who correctly identified certain basic tastes did not consistently show higher or lower liking of that particular taste. Furthermore, there was no effect of gender on liking observed in this study (F = 0.31, *P-value* greater than 0.05).

4. Discussion

4.1. Children's taste identification ability

This study revealed that children were able to identify the basic tastes of sweet, salty, sour and bitter in unfamiliar foods with congruent results to a trained sensory panel as can be seen in the CA mapping. The basic taste responses of the children showed to be close to that of the trained panel for the whole sample set of unfamiliar foods. This relation was further highlighted through a significantly high RV coefficient between the children and the trained panel suggesting a high correlation and agreement in the basic taste identification between them. This result is aligned with the study from Laing et al. (2008) which reported that children were able to identify the four common tastes of salty, bitter, sour and sweet. Furthermore, results from James, Laing, Jinks, Oram, and Hutchinson (2004) also indicate that 8–9-year old children have the same response function of taste intensity as adults, particularly for sweet taste, concluding that children of this age had reached maturity for their suprathreshold perception of sweet stimuli. The taste identification study conducted by Mustonen et al. (2009) showed that sweet taste was the easiest and the most familiar taste to be identified by 7–11-year-old children, while bitter and umami was the most difficult to be identified by this age group. This corroborates our results where the taste identification ability of children was the highest for the sweet taste particularly when the sweet taste was shown to be the single dominant taste in the unfamiliar food sample and showed to be low in bitter taste.

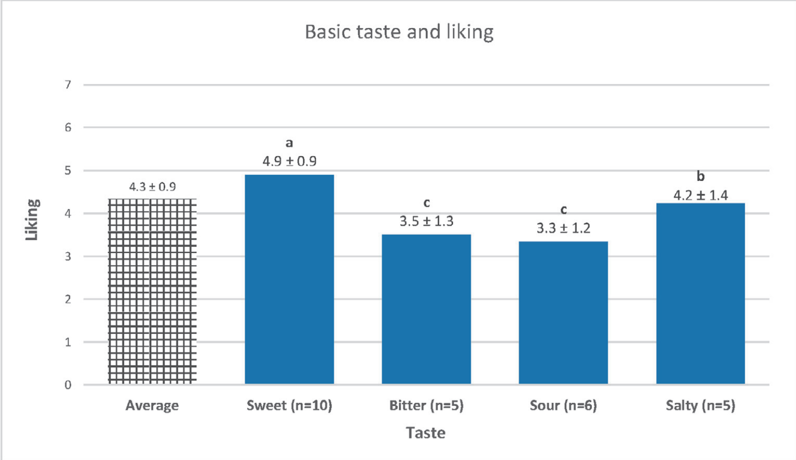

Fig. 7. Mean liking for food samples per dominant basic taste. Different letters indicate significant differences in Tukey's pairwise comparison test ($p < 0.05$), (n = number of actual dominant tastes occurred in food samples).

However, the children and trained panel seem to differ with regard to bitter taste as can be seen in Fig. 3. The children showed to have a lower average of taste identification score in food samples combining bitter and sweet dominance. They perceived root beer and goat cheese to be dominantly bitter whereas they should be sweet and sour, respectively. Root beer, known as vørterøl is a Norwegian traditional non-alcoholic malt beverage that has a sweet malty taste balanced with the fizzy sensation from the carbonation process of CO_2 (Carlsberg, 2019). The research by Lederer, Bodyfelt, and McDaniel (1991) suggested that the carbonation level generates a significant effect on bitterness and sourness perception. Moreover, another study by Hewson, Hollowood, Chandra, and Hort (2009) also revealed that the perception of bitter aftertaste was primarily driven by the CO_2 level. This perception was further enhanced with the presence of acid that is commonly added in carbonated beverages. The carbonation process was also reported to be able to supress sweet taste (Hewson et al., 2009) and this may have an effect on children's taste perception of the root beer.

As for the goat cheese, lactic acid has been reported as the main organic acid compound that contributes to the sour taste in this product (Gámbaro et al., 2017). However, in this study the children reported that the goat cheese tasted bitter rather than sour. Children reportedly have a heightened sensitivity and rejection response to bitter tastes biologically (Mennella et al., 2013). This might be one of the reasons why they perceived bitter taste to be stronger than sour taste. In addition, children's perception of the bitter taste can increase as the low to mild intensity of sour taste has an enhancing effect on the bitter taste (Breslin, 1996) particularly when both of these tastes appear in combination. Alternatively, it might have been difficult for the children to correctly name the acidic sensation of goat cheese as sourness. It has been reported that also adults commonly mistake bitterness for sourness and that the issue is even more frequent in children (Guinard, 2000).

Furthermore, the low identification of bitter taste might be due to the weak bitter taste intensity present in the food samples such as in goji berry and water chestnut. In this study, the goji berry was served as dried fruits and thus the bitter taste was not as strong as in the fresh berries, as the polysaccharides contributing to the sweet taste are more concentrated in the dried berry (Ma et al., 2019) possibly resulting in this food being identified as sweet by some of the children. As for the water chestnut, the canned version was used in this study and did not have a strong bitter taste which could be why they were not often identified as bitter by the children. In addition, most of the food that represented bitter taste had binary mixture with sour taste, such as in fermented milk, grapefruit and kumquat in which sourness was perceived more dominant in comparison to bitter (Fig. 5). This resulted in a higher correctness score for the sour taste (9.4 ± 4.1 SD) compared to the bitter taste (5.1 ± 4.3 SD), and explains the positive correlation between bitter and sour attributes in the PCA (*Pearson* = 0.36, $p < 0.05$). The low intensity may also affect the low identification score for the sweet taste in durum wheat semolina and bulgur. These foods are made from wheat (Elias, 1995) which mainly consist of carbohydrate content that makes them have an elicit sweet taste (Lim & Pullicin, 2019). However, the sweet taste in these products tend to have a low intensity which makes them popular to be cooked together with meat or vegetables to add more flavour and tastes (Rosentrater & Evers, 2018). This low intensity might contribute to lower the identification score ability of children for the sweet taste.

Oram and colleagues (2001) reported that children from the age of 8–9 year old have reliable sensitivity in identifying basic taste of single taste modality, however, the same study also revealed that they were not able to recognize the presence of binary taste combinations, resulting in them choosing the strongest or the most appealing taste based on their perception. In the two-component combination, each of the taste qualities is usually suppressed and perceived as less intense than when they are tasted separately (Bartoshuk, 1975). Sour taste is suppressed the least when other taste components are available in taste combination (Keast & Breslin, 2003). The combination of sour and bitter will enhance each other at low concentrations but at moderate concentrations the bitter taste will be suppressed, and sour taste enhanced (Bartoshuk, 1975). However, this depends on the concentration level (Breslin, 1996) and the taste compound (Keast & Breslin, 2003) used in the experiment. In this study, children identified sour taste more easily than bitter taste, because sour tends to be stronger in the taste mixture of the food samples. This conclusion is aligned with the previous study from James et al. (1999) who also stated that children might get distracted in taste modalities measurement when complex models are introduced. Considering the occurrence of basic taste combinations and the low intensity of dominant tastes in certain food samples, it would be important to also measure taste intensity in future studies.

This binary combination phenomenon was also observed in sweet taste. When sweet taste was present with other tastes such as salty in

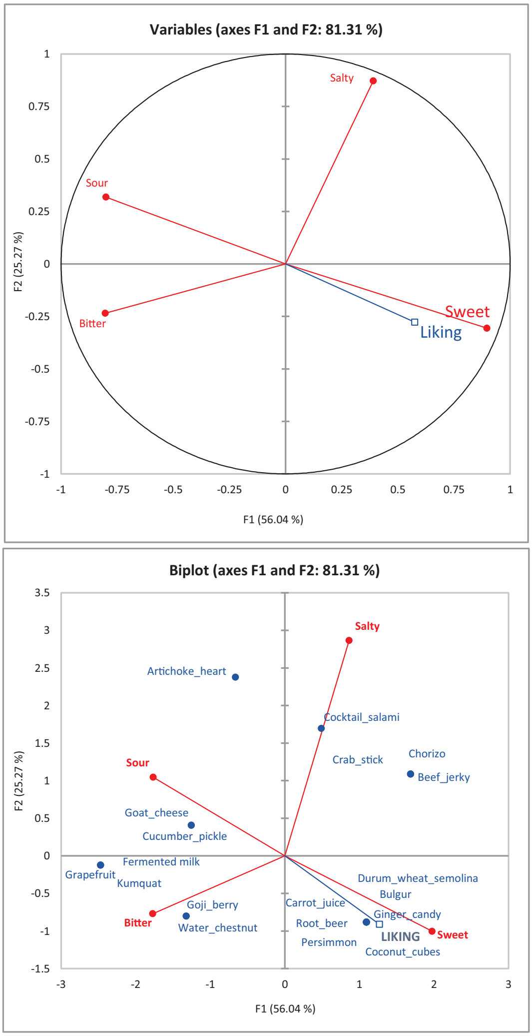

Fig. 8. PCA analysis showing the correlations between dominant basic tastes and children's liking for the food samples.

chorizo beef jerky, and crab stick, children's identification ability showed to be lower compared to when sweet taste was solely present such as in persimmon or in coconut cubes. In salty-sweet food samples, the children perceived the salty taste to be more dominant than the sweet taste, thus resulting in lower correctness scores for the sweet taste (4.4 ± 3.9 SD) than for salty taste (9.5 ± 4.0 SD). In addition, root beer was perceived to be more bitter than sweet and this contributes in lowering the general correctness score for sweet taste. This is in line with the conclusion from Oram et al. (2001) who suggested that children were able to identify single taste but not binary mixtures of tastes. Moreover, in the case of beef jerky, and chorizo, the salty taste was perceived to be more dominant than the sweet taste, while for crab stick there were several children who chose either sweet or salty as dominant, but not in combination. These meat-based products are salty due to the curing and aging process that helps prolong shelf life (Feiner, 2016). Furthermore, high liking scores were observed for the salty foods in this study. This is in line with a review study from Hoffman, Salgado, Dresler, Faller, and Bartlett (2016) on salt preferences, which suggested that young children and adolescents preferred higher concentrations of sodium chloride. In addition, a study involving 4–6 year-old children also showed that children have a good ability to identify salty taste in the model food of saltine crackers and cheese (Wendin et al., 2017).

4.2. Children's taste identification ability and liking

It has been reported that sweet taste is the most liked taste (Ahrens, 2015; Hoffman et al., 2016) and biologically preferred by children from infancy (Mennella & Bobowski, 2015). This is aligned with the results obtained from this study showing that the food samples that were dominantly characterized by sweet taste significantly had the highest liking scores (mean 4.9 ± 0.9 SD). According to the PCA, the presence of sweet taste showed to have a significant positive correlation with children's liking. On the contrary, the food samples that were dominantly characterized by sour taste led to the lowest liking scores. This supports previous results from Liem and de Graaf (2004) who suggested that children aged 6 to 11 years old did not prefer a higher level of sour taste orangeade even after repeated exposure of sour taste. Moreover, according to Hoffman et al. (2016), sour taste in general is also less preferred than sweet or salty tastes. The fact that sour and bitter tastes appeared in combination in several food samples in this study might also have affected children's acceptance (Oram et al., 2001; Keast & Breslin, 2003).

No correlation was found between basic taste identification ability of children and their liking, indicating that children who correctly identified a certain basic taste did not systematically show higher or lower liking for that specific taste. This corroborates previous studies from Vennerød et al. (2018) and Lanfer et al. (2013) suggesting that children's taste sensitivity does not solely determine their taste preferences. It has been extensively investigated that many other factors contribute to children's taste preferences and eating behaviour such as taste exposure (Nicklaus, 2016), demographics and family condition (DeCosta, Moller, Frost, & Olsen, 2017; Vennerød, Almli, Berget, & Lien, 2017), and socio-cultural environments (Lanfer et al., 2013). Moreover, basic taste sensitivity has also been reported to have a strong correlation with genetic factors (Mennella et al., 2005; Joseph, Reed, & Mennella, 2016) contributing to large differences of taste sensitivity between individuals (Hartvig et al., 2014). Further, there was no gender effect observed in this study, corroborating the previous study from James, Laing, and Oram (1997) reporting that taste sensitivity is not affected by gender in 8 to 9-year old children.

4.3. Methodological approach

To our knowledge, this is the first study measuring basic taste identification ability of preadolescent children in unfamiliar food samples. Food familiarity was reported to have influenced children's food perception (Laureati & Pagliarini, 2019). Removing the familiarity aspect will make the evaluation more difficult for the children as they did not have the memories to recall the taste of the foods (Higgs, 2011) and making them rely on their taste sensitivity only. In this study it was important to select unfamiliar foods that had distinct basic taste(s) dominance. However, the selection of the unfamiliar foods was challenging. It was difficult to select foods that fulfilled the unfamiliarity aspect as well as other aspects such as availability on the Norwegian market, the capacity to not trigger disgust, the practicality of being easily prepared and the possibility to be served at room temperature. The use of real food samples instead of model foods enhanced the relevancy of this sensory study by providing complex sensations of basic taste combinations in addition to odour, texture and aroma variations.

The limitation of the study is that only dominance, but not the intensities of the basic tastes were evaluated in the food samples. In addition, umami was not included in the measurement to the children which could be potentially present as a dominant sensation for the meat based food samples and might affect children's liking (Roininen, Lähteenmäki, & Tuorilla, 1996; Lanfer et al., 2013). The umami taste itself is not familiar in Europe (Cecchini et al., 2019). This taste is commonly labelled as salty even though umami has been accepted as the fifth basic taste and has a different receptor from salt (Kurihara, 2015). Inclusion of umami in future studies may however require a training session to ensure that the children are familiar with this taste and term.

5. Conclusion

This study aimed to investigate the ability of 10 to 11-year old children in identifying the basic tastes of sweet, salty, sour and bitter in unfamiliar food samples. In this study, the children relied solely on their taste perception as effects of context memories that may occur in familiar foods could not occur with unfamiliar foods. The results showed that children were able to identify the basic tastes of unfamiliar food samples with good congruency to a trained panel. This supports previous research which concluded that children have a good ability in perceiving taste stimuli in sensory testing. However, in our study, this ability was shown to be negatively affected by the co-presence of dominant tastes. Further, there was no association found between taste identification ability and children's liking. Future research may investigate the associations between basic taste identification ability and children's taste sensitivity thresholds. For future studies, it is recommended to consider the taste intensity in the food samples and to include umami, since umami contributes to the savoury taste of foods and might affect children's perception and liking. Finally, further studies are needed to better understand the role of basic taste perception abilities in children's food acceptance.

Credit authorship contribution statement

Ervina Ervina: Methodology, Formal analysis, Data curation, Investigation, Writing - original draft, Visualization. **Ingunn Berget:** Methodology, Supervision, Writing - review & editing. **Alexander Nilsen:** Conceptualization, Methodology, Investigation, Resources, Data curation. **Valerie L. Almli:** Conceptualization, Methodology, Data curation, Supervision, Writing - review & editing.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.foodqual.2020.103929.

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Paper 2

foods

MDPI

Article

Investigating the Relationships between Basic Tastes Sensitivities, Fattiness Sensitivity, and Food Liking in 11-Year-Old Children

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Abstract: This study investigates the relationships between basic tastes and fattiness sensitivity and food liking in 11-year-old children. The basic taste sensitivity of 106 children was measured using different methods, namely detection (DT) and recognition (RT) thresholds, and taste responsiveness. Caffeine and quinine (bitter), sucrose (sweet), citric acid (sour), sodium chloride (salty), and monosodium glutamate (umami) were investigated for DT and RT at five concentrations in water solutions. In addition, taste responsiveness and liking were collected for the high-intensity concentrations. PROP (6-n-propylthiouracil) responsiveness was tested on paper strips. Fattiness sensitivity was measured by a paired comparison method using milk samples with varying fat content. Liking for 30 food items was recorded using a food-list questionnaire. The test was completed in a gamified "taste detective" approach. The results show that DT correlates with RT for all tastes while responsiveness to PROP correlates with overall taste responsiveness. Caffeine and quinine differ in bitterness responsiveness and liking. Girls have significantly lower DTs than boys for bitterness and sweetness. Food liking is driven by taste and fattiness properties, while fatty food liking is significantly influenced by fattiness sensitivity. These results contribute to a better holistic understanding of taste and fattiness sensitivity in connection to food liking in preadolescents.

Keywords: taste sensitivity; basic tastes; fattiness; food liking; preadolescent; caffeine; quinine; gamification

1. Introduction

Taste is of primary influence on food selection particularly in children [1–3]. It is one of the key factors determining food palatability and liking, which contribute to food intake [4]. Taste is also reported to affect food choices in children aged 12–13 and significantly determines food acceptance in 7–11-year-old children [5,6].

Children are individually different in perceiving tastes [7]. Taste sensitivity is defined as the individual ability in responding to taste stimuli [8] which could be measured by different methods such as detection threshold (DT), recognition threshold (RT), taste responsiveness, and fungiform papillae (FP) density [9]. In addition, sensitivity to PROP (6-n-propylthiouracil) has been associated with other taste responses, which makes this test commonly used in taste sensitivity studies [10]. The DT focuses on low concentrations of taste stimuli and is obtained at the point where the concentration of the taste stimulus can be discriminated from water [9]. As the concentration is further increased, RT is obtained as the point where the taste is perceived and identified [11]. Subjects can be separated into taste-sensitive and nonsensitive groups according to their DT or RT as previously proposed in adults [12] or in children aged 7–14 years [7]. Taste responsiveness is the subject's rating of perceived intensity to taste stimuli above the threshold level, also known as the suprathreshold intensity [13]. The 6-n-propylthiouracil, also known as PROP, is a chemical compound commonly used to measure subjects' responsiveness to bitterness [14]. However, responsiveness to PROP may not reflect responsiveness to all bitter compounds; this measure is specifically related to the genetic variants of taste receptor TAS2R38 for bitter perception [10,15]. Indeed, PROP is chemically similar to phenylthiocarbamide (PTC) and sensitivity to these compounds was reported to be associated with the TAS2R38 receptor [16–19]. Sensitivity testing to PROP can be conducted using water solutions [20,21] or impregnated paper [22,23]. People can be classified into supertasters, medium-tasters, and nontasters according to their responsiveness to PROP, i.e., their PROP phenotype. This classification is based on intensity ratings perception of the stimulus on a Labeled Magnitude Scale (LMS), and the application of established cut-off points that define the taster categories [23]. Subjects categorized as tasters perceive a higher bitter sensation of PROP compared to a nontaster [14,21]. The quantification of fungiform papillae (FP) has also been used to infer taste sensitivity. However, there is a concern related to using this method, as recent studies involving large population samples concluded that FP density does not directly correlate to taste sensitivity [24–26].

There are five basic tastes—sweet, sour, salty, bitter, and umami—that, respectively, relate to different receptors and mechanisms of responses [27]. In addition, the taste of fat (also called oleogustus) has been suggested as the sixth taste modality [28], with a gustatory pathway devoted to the perception of lipids [29]. The association between the different basic tastes and their taste receptors has been widely investigated, with the results suggesting that genetic variants may contribute to individual taste sensitivity [15,30]. Differences in taste sensitivity contribute to a variety of eating practices and food choices [31]. Taste sensitivity is shown to influence the willingness of 9–11-year-old children to consume fruits and vegetables [32] and significantly affects their acceptance of new foods [33]. Moreover, sensitivity to PROP is reported to affect the acceptance of sweet and fatty foods [34], and children aged 4–5 years with lower bitter taste sensitivity are reported to have a higher vegetable acceptance [35].

Regarding sweet taste, previous research has reported that sweetness sensitivity correlates with an increase in the liking of sweet food. This was investigated using sweetened apple juice in 6–9-year-old children [36]. The sweet sensitivity of 4–6-year-old children has also positively been correlated with their preference for sweetened beverages [37]. On the opposite end, a bitter taste has been associated with food rejection in children [38,39]. Moreover, 4–5-year-old children who were sensitive to PROP have been shown to have a lower acceptance for broccoli and cheese compared to nonsensitive children [21]. In a review on children's perception of saltiness, Liem [40] concluded that saltiness plays an important role in children's liking for a selection of salty foods, but that saltiness sensitivity does not influence children's real consumption of salty food products. To our current knowledge, there are few studies about sourness sensitivity in children. Unlike the other basic tastes that consistently have been reported to influence food palatability, the literature indicates that sour taste does not significantly affect liking and preference in nine-year-old children, even after repeated exposure of this taste [41]. Moreover, a recent taste sensitivity study involving large samples of children aged 6–9 in Europe did not include sourness in the evaluations [42]. Further, umami has been reported to enhance palatability and acceptance of foods [43]. Sensitivity to umami has been reported to be significantly different in 13–16-year-old children according to their weight [44]. The study of the recognition threshold for this taste requires a training session [45] due to unfamiliarity and confusion between umami and saltiness [45,46]. In addition to the basic tastes, fattiness sensitivity has been highlighted to affect the liking and consumption of fatty foods [47,48]. However, the correlation between fat sensitivity and food liking in children seems to be inconsistent [49], particularly when weight status is involved. Previous investigations of fat sensitivity in children often used dairy samples such as milk, cheese, or pudding varying in fat content [50,51].

Although the matter of taste sensitivity and food liking has widely been investigated over the decades, it is still uncertain how different taste sensitivity measures relate to each other and to food liking. Moreover, different methods for measuring taste sensitivity may lead to different results, preventing easy results comparison between studies. A review by Cox et al. [49] suggested the need to measure the relationship between sensory sensitivity, fattiness, and liking. Earlier research results on the relationship between taste sensitivity and food liking are inconsistent [49] and studies involving preadolescent subjects are still limited [52]. The objective of this study is to investigate the relationships of basic tastes and fattiness sensitivity with food liking in 11-year-old children. By understanding the role of basic tastes and fattiness sensitivity in food liking, we may provide insights on how to encourage preadolescents to choose healthier food options, since this group has been reported to have selective eating [53]. To our knowledge, this is the first study on taste sensitivity investigating the relationship between five basic tastes as well as fattiness and food liking conducted in preadolescents. Moreover, different methods were applied including DT, RT, taste responsiveness, and PROP responsiveness testing to measure taste sensitivity. In addition, water solutions of both caffeine and quinine were utilized in this study to characterize sensitivity to bitterness, since subjects may have different sensitivity thresholds for different bitter compounds [54,55].

2. Materials and Methods

2.1. Participants

A total of 118, sixth-grade children were invited from two primary schools in Ski county, Norway. Both the children and their parents were provided with short information regarding the study activities in the form of a flyer. Signed written consent from the children and their parents was required to participate in the study. In addition, the children's verbal consent was enquired at the beginning of the test. A total of 107 children returned the consent form and participated in the sensory testing. One of the subjects did not finish the test, resulting in 106 children involved in the data analyses. The schools received rewards for the benefit of the children for their participation, however, each child's participation was voluntary. The ethical approval of this study has been granted by The Norwegian Center for Research Data (NSD) No. 747124 and refers to the Declaration of Helsinki, while data protection has followed the General Data Protection Regulation (GDPR).

2.2. Test Procedure: The Taste Detective Game

When conducting sensory testing with children, it is important to implement a test procedure that is appropriate for the children's age and psychosocial and cognitive ability [56]. In addition, it needs to be fun and engaging for them [52]. Therefore, a gamification concept was inserted into the testing procedure and introduced to the children as a game called the "taste detective". In this sensory game, a short story was narrated, and the children were asked to conduct different tasks as taste detectives. The first task aimed to measure the children's responsiveness and liking to basic tastes, the second task measured children's basic tastes DT and RT, the third task measured fat sensitivity, and the last task measured children's responsiveness to PROP. All the measurements will be explained in the following sections. To evaluate the gamification concept, the children rated how fun and how difficult the sensory game was at the end of the test. This was recorded on a seven-point pictorial scale labeled with "not fun at all!" to "very fun!" and "very difficult!" to "very easy!".

The children's age, gender, and self-reported hunger levels were also recorded. The children's hunger levels were measured using a seven-point pictorial scale anchored from "not hungry at all" to "very hungry". This practice was applied because previous research has shown that hunger may influence taste sensitivity [57] and the test was conducted at different times (10:30–11:15 and 11:30–12:15 for School A, and 12:30–13:15 and 13:00–13:45 for School B). Testing was conducted across 6 sessions with around 20 children for each testing time.

Most of the instructions were arranged online and the children's responses were recorded with the aid of tablets. At the beginning of the test, we explained the rules of the game (i.e., performing the test quietly, not talking to one another, rinsing the mouth with water in-between samples, etc.) and what each task involved. It took the children around 30–45 min to finish all the tasks. All the tests were conducted in the children's respective schools and classrooms. There were four adults present during the testing time: one person explaining the game and rules, two research assistants helping with the samples for the children, and one teacher.

2.3. Samples

The subjects' basic tastes sensitivities to sweet (saccharose), sour (citric acid), salty (sodium chloride), umami (monosodium glutamate), and bitter (caffeine and quinine) were evaluated based upon five concentration levels each (Table 1). All the taste compounds are food grade and were purchased from Merck Kga, Germany. The samples were prepared by dissolving the tastant in tap water in the sensory laboratory at Nofima (Ås, Norway) a maximum of two days before the evaluation. Around 10 mL of the sample solutions were served to the children at room temperature.

Table 1. Basic taste concentration levels.

Taste	Taste Compound	Level 1 (g/L)	Level 2 (g/L)	Level 3 (g/L)	Level 4 (g/L)	Level 5 (g/L)
Sweet	Saccharose	3.0	6.0	9.0	12.0	16.0
Sour	Citric acid	0.05	0.1	0.16	0.2	0.25
Salty	Sodium chloride	0.2	0.4	0.8	1.2	1.6
Umami	Monosodium glutamate	0.1	0.3	0.6	1.2	1.5
Bitter	Caffeine	0.05	0.1	0.15	0.2	0.27
Bitter	Quinine	0.0014	0.0017	0.0023	0.0038	0.006

The concentration levels for sweet, salty, umami, and caffeine-bitter followed the study from Knof et al. [58]. These concentration levels had been used in a large population study in Europe to measure taste sensitivity in 6–9-year-old children [42]. The sour taste concentrations followed the study from Myhrer et al. [59] while the bitterness level of quinine was adapted from Vennerød et al. [60]. All the levels of the sample solutions were first pretested by colleagues at the sensory department at Nofima, adjusted, then piloted with 42 children aged 11–12-years. The results showed that the selected sample solutions covered a suitable concentration range for measuring both DT and RT, and matched one another in concentration level intensity across the basic tastes (results not reported here).

2.4. Taste Responsiveness and Taste Liking

The children's taste responsiveness was measured at the beginning of the test and using the strongest level (i.e., Level 5, see Table 1) of each taste compound in 10 mL servings. This level was expected to be clearly perceived by the majority of the children. The children evaluated all the basic tastes including two bitter compounds of caffeine and quinine in a randomized balanced order. Their responses were recorded in an unstructured line scale labeled with "weak" and "strong" and was then scaled into 0–100 for data analysis purposes. For this task, the cups were labeled with the names of the basic tastes. The liking of basic tastes in water solution at the same concentration level was also recorded in a seven-point pictorial hedonic scale. The children were provided a short explanation on how to use the line scale (i.e., by placing a mark on the line according to the strength of their perception after tasting the sample) and the pictorial scale (i.e., by choosing a happy or grim face according to the degree of their liking). This first session also aimed to familiarize the children with the basic tastes' names and sensations. This was aimed to reduce the children's confusion between the basic tastes in the following recognition task [61], particularly for salty-umami and sour-bitter [13]. Such confusions have been reported to often occur in children aged 7–11 years [45].

2.5. Detection and Recognition Test

The children's taste sensitivity was also measured using detection and recognition thresholds, DT and RT. In this evaluation, they were told to solve six taste mysteries presented with different symbols. One symbol represented one basic taste and consisted of a series of five cups labeled from 1 to 5, corresponding to the increasing concentration levels of the taste (Table 1). All samples were given to the children at the same time in 10 mL servings, in addition to an identified cup of plain water for reference. The children were instructed to perform the tasting in a staircase order for one series (i.e., from Cup 1 to Cup 5) and could repeat their tasting for each cup. They had to identify the taste of each cup and would record their answers by dragging each corresponding cup on their tablet screen into the right taste box. Seven taste box options were offered: "sweet", "sour", "salty", "bitter", "umami", "water", and "I don't know". Note that all seven answer options were available for each cup at any time during the whole test. For each specific concentration level, we assumed that children who answered "water" could not detect any taste (tastant under detection threshold). DT was obtained when the subject could start to differentiate the sample from water, while RT was obtained when the child correctly identified the taste. Last, we assumed that children who either answered "I don't know" or wrongly identified the taste quality, could detect the tastant; this level was therefore recorded as their DT. On their tablets, the children could freely place each cup in any taste box according to their own perception, without any limitation regarding the number of cups that could be placed in each box. Moreover, the children were not told that each series of five cups all carried the same taste, so they could freely attribute different tastes to cups of a given series. Once a taste series of five cups was completely evaluated, a break was provided with a few items from the food liking questionnaire (see below). Then, the on-screen instructions indicated to the child which symbol they should categorize next. It was not possible for the child to reconsider cups from the previous symbols.

In this test, we informed the children that there were no right and wrong answers, as this depended on their own perception. This point was strongly reminded and inserted as one of the game rules. Moreover, the children had to compare the samples with water and to rinse their mouths between tasting. They could spit out the samples in spitting cups to avoid being bloated during the evaluation. The taste series were tested in a randomized balanced order across children.

2.6. PROP Responsiveness

PROP responsiveness was measured by a paper strip (Precision Laboratories, Inc., Northampton, United Kingdom). The use of this paper strip was adapted from a method by Pickering et al. and Oftedal and Tepper [23,62]. The children were asked to place the strip in their mouth and hold it for 30 s before rating the bitterness intensity using the LMS [63]. Prior to this task, the children were provided with the instructions on how to use the LMS by using examples of foods that have extreme and mild sensations such as syrups and mineral water, salted potato chips and a spoon of salt, a spoon of wasabi, etc. [64]. The children were classified based on their LMS rating into nontasters (if they rated the bitterness $\leq$ 13 mm on the LMS), medium-tasters (14–67 mm), and supertasters (>67 mm) [23]. The test was allocated at the end of the whole testing session to refrain supertasters from being demotivated for further participation. The children received water and fresh fruits (grapes) after this task to clear their mouth from any unpleasant lingering sensation.

2.7. Fattiness Sensitivity Test

A paired comparison method adapted from Alexy et al. [50] was used to measure fattiness sensitivity. Four milk samples were tested in pairs with 0.5% (low), 1% (medium), and 1.5% (high) fat content differences for each pair (Table 2). All the milk samples were purchased from a local supermarket. There was no modification to the fat content for each milk sample except for the 2% fat milk, which was obtained from mixing the 3.5% and 0.5% samples in a 1:1 ratio. The milk pairs were presented in disposable cups and labeled with a geometric symbol, followed by a unique three-digit random number for each milk sample. The children's task was to identify the fattiest milk sample in each pair, in addition to the sample they liked the most. To explain the fatty taste, the children cited examples of fatty foods (i.e., cream, butter, etc.) prior to the evaluation. All the pairs were served at the same time. Both the pairs and the milk samples within pairs were tested by the children in a randomized order. The children were told to rinse their mouth with water between testing the milk samples. Those who reported having a milk allergy and/or lactose intolerance or who declined to taste the milk samples were excluded from the milk evaluation (19 excluded, leading to n = 87 subjects who completed the task).

Table 2. Milk samples for the fat sensitivity test.

Pair	Fat Content Differences	Samples
Low	0.5%	0.5% fat milk 1.0% fat milk
Medium	1.0%	1.0% fat milk 2.0% fat milk
High	1.5%	2.0% fat milk 3.5% fat milk

2.8. Food Liking Questionnaire

The children completed a food liking questionnaire which consisted of 30 different food items representing five different basic tastes, and fattiness (the list of the food items is presented in Supplementary Material Table S1). The selected food items and their basic tastes and fattiness profiles were based on a study by Martin et al. [65], and were relevant within the Norwegian diet as they were listed in the Norwegian dietary survey [66]. The children were asked about the familiarity of five random food items by either stating "I have tasted it" or "I have never tasted it". If they had tasted the item before, they then scored their liking using a seven-point pictorial hedonic scale. These practices were conducted six times between the basic taste sensitivity measurements, aimed to provide a short break from the tasting task as well as reducing boredom to cover the list of 30 food items. The food items were evaluated in a randomized balanced order.

2.9. Data Analysis

Multiple Factor Analysis (MFA) was applied to explore the relationship between taste sensitivities measured by different methods. The liking of the basic tastes in water solutions (Level 5 concentration) was included in the MFA as supplementary variables.

The overall DT, RT, and taste responsiveness scores were computed by averaging DT levels, RT levels, and taste responsiveness scores, respectively, across the six compounds tested in water solutions. This was aimed to observe the relationship between each measurement of taste sensitivity. Pearson correlations were computed between the different sensitivity measurements and between taste compounds. The different taste sensitivities (DT, RT, and taste responsiveness), as well as the liking of basic tastes in water solution, were modeled using linear mixed models. This analysis was aimed to explore the effect of taste quality, hunger level, and gender (fixed effects) on taste sensitivity or liking of basic taste in the water solution sample. In these models, a child nested within gender was included as a random effect. In addition, PROP responsiveness was included as a continuous variable. The children's hunger levels across schools and testing times were also compared and analyzed using a Student's t-test.

Linear mixed models were also applied to test the effect of taste sensitivity on food liking. Taste sensitivity (as measured by DT or taste responsiveness), taste quality, gender, and hunger level were included as fixed factors, whereas child nested within gender was included as a random effect. In addition, PROP was added as a continuous variable. Note that RT was not investigated in such a model as it was not shown to be influenced by any of the explanatory variables from the previous mixed model analysis. Further, Principal component analysis (PCA) was applied to map the children's food liking with the children's liking scores as columns and food items as rows. The food liking scores were double-centered prior to the analysis as this enables us to better observe individual differences [67]. The taste profiles of the foods were coded as binary variables for each of the basic tastes and fattiness (+1 if present, 0 if not present) and included as supplementary variables. The children were grouped into three liking groups based on PC1 and PC2 loadings, and a two-way ANOVA was then conducted to analyze the group effect and gender effect on taste sensitivity measured by DT for each taste.

Based on their response in identifying the correct milk pair, the children were categorized into sensitive and nonsensitive groups with respect to fattiness. The children who correctly answered the pairs from low- to high-fat levels in a staircase order (as seen in Table 2) were allocated to the fat-sensitive group (this includes those who correctly identified all the pairs; those who correctly identified both medium and high pairs; and those who correctly identified the high-fat pair only). The remaining children (those who answered all pairs incorrectly, or those who answered other than the above-mentioned pattern) were categorized as the non-fat-sensitive group. This practice was carefully applied to eliminate the chance of guessing and inconsistent answers from the children, as our data showed an inconsistency from several children who correctly classified the low-fat pair (0.5%) but were not able to identify the high-fat pair (1.5%). The effect of fattiness sensitivity on the liking of fatty foods between the groups was analyzed using Analysis of Covariance (ANCOVA), with PROP involved as a continuous explanatory variable.

Pairwise comparisons were conducted using Tukey's post hoc test with a significance level set to $\alpha = 0.05$. All statistical analyses were computed using XLSTAT Sensory version 2020.1.2 (Addinsoft, France).

3. Results

3.1. Subject Characteristics and the Taste Detective Game Approach

Forty-six percent of the participants were boys while 54% were girls. Ninety-four percent of the children were 11-year-old (mean age = 10.9 years). There was no significant difference regarding the children's hunger level between different schools and testing times. Moreover, the hunger level did not contribute to a significant effect in any of the models and was therefore excluded from further results. The taste detective game was rated as a fun activity by 84% of the children (Table 3) and 63% of the children rated the game as easy to conduct.

3.2. Children's Basic Tastes Sensitivity and Liking in Water Solutions

The classification of children's taste sensitivity based on the PROP phenotype resulted in 13% nontasters, 51% medium-tasters, and 36% supertasters. Furthermore, the first two factors in MFA weighed for 27.1% of the variability (Figure 1). The DT showed to be strongly correlated with RT while the taste responsiveness had a high correlation with PROP responsiveness in the MFA map, indicating that DT and RT seemed to measure a different dimension of sensory perception from taste responsiveness and PROP. The liking of the Level 5 basic taste solutions (see Table 1) did not correlate well with any of the sensitivity measures, indicating that this affective response to taste is only partially dependent on objective detection, recognition, and responsiveness measures. The sweet and sour tastes were recorded as the most liked while umami and salty were the most disliked from the water solution samples (Table 4). Gender had a significant effect on the liking of basic taste in the water solutions, indicating a higher liking for sweetness ($p = 0.004$) and bitterness of quinine ($p = 0.07$) for boys compared to girls.

Table 3. The participants' characteristics and evaluation of the game.

Variables	Participants (n = 106)
Gender	Boy 46% (n = 49) Girl 54% (n = 57)
Age	10-year-old 5% (n = 5) 11-year-old 94% (n = 100) 12-year-old 1% (n = 1)
PROP (6-n-propylthiouracil) status	Nontaster 13% (n = 13) Medium-taster 51% (n = 55) Super-taster 36% (n = 39)
Hunger level (scale 1–7) *	School A (n = 61) 3.5 ± 1.4 SD School B (n = 45) 3.9 ± 1.9 SD
Enjoyment of the game	Not fun 6% (n = 6) So so 10% (n = 11) Fun 84% (n = 89)
Difficulty of the game	Difficult 15% (n = 16) So so 22% (n = 23) Easy 63% (n = 67)

* No significant difference between schools and testing times ($p > 0.05$).

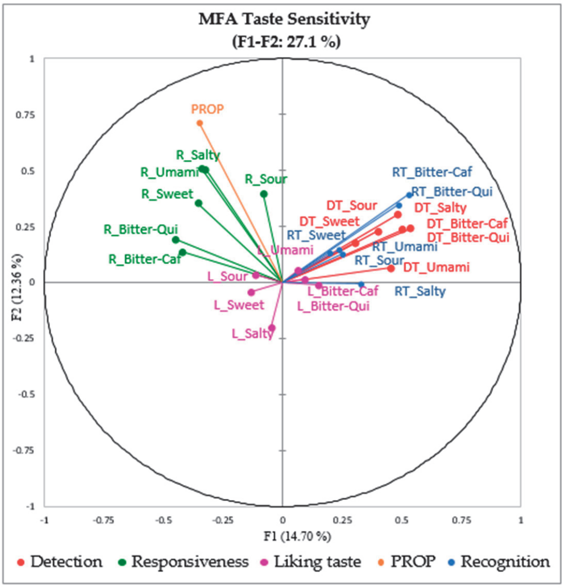


Figure 1. MFA of taste sensitivity and liking measures, included as supplementary variables (R = responsiveness, DT = detection threshold, RT = recognition threshold, L = liking of taste solutions).

Based on Pearson correlation coefficients (r), all the taste sensitivity measurements were significantly correlated to one another, except for PROP responsiveness and RT. There was a significant positive correlation found between overall DT and RT scores ($r = 0.30$, $p < 0.001$), and between overall taste responsiveness and PROP ($r = 0.13$, $p = 0.001$), with each of the basic tastes individually showing similar results. Taste responsiveness to salty and to umami showed a significant positive correlation with PROP responsiveness. Moreover, overall DT and RT were negatively correlated with taste responsiveness (r = −0.14, p = 0.001 for DT; r = −0.11, p = 0.006 for RT). We may however note that although significant, all the correlations found were rather weak.

Table 4. Children's taste sensitivity (responsiveness, DT, and RT) and liking of basic taste solutions.

Taste	Responsiveness (mm; Mean ± SD)	Detection (Mean ± SD)		Recognition (Mean ± SD)		Liking [3] (Mean ± SD)
		Level [1]	Conc. (g/L) [2]	Level [1]	Conc. (g/L) [2]	
Sweetness	44.6 ± 29.6 [a,b]	1.6 ± 0.7 [b,c]	4.78 ± 2.09	3.2 ± 1.2 [c]	9.81 ± 4.0	4.1 ± 1.9 [a,b]
Sourness	30.6 ± 23.9 [c,d]	1.9 ± 0.9 [a,b]	0.09 ± 0.05	3.7 ± 1.3 [a,b]	0.19 ± 0.06	4.2 ± 1.6 [a]
Saltiness	42.7 ± 28.2 [a,b]	1.5 ± 0.7 [c]	0.32 ± 0.20	3.4 ± 1.3 [b,c]	0.97 ± 0.49	2.6 ± 1.5 [d,e]
Bitterness (caffeine)	23.8 ± 25.9 [d]	2.3 ± 1.4 [a]	0.12 ± 0.07	3.9 ± 1.4 [a]	0.21 ± 0.07	3.5 ± 1.5 [b,c]
Bitterness (quinine)	36.9 ± 31.8 [b,c]	2.2 ± 1.3 [a]	0.002 ± 0.001	3.9 ± 1.3 [a,b]	0.004 ± 0.002	3.1 ± 1.6 [d]
Umami	53.8 ± 29.6 [a]	1.8 ± 1.2 [b,c]	0.27 ± 0.21	3.7 ± 1.3 [a,b]	0.99 ± 0.51	2.2 ± 1.4 [e]

[1] Mean levels 1–5 (Table 1). [2] Mean concentrations in g/L, calculated based on taste compound concentrations corresponding to the mean level (Table 1). [3] Mean liking (scale 1–7) was measured on basic taste solutions of Level 5 concentration (Table 1). Different letters in detection and recognition (level) columns indicate a significant difference at $p < 0.05$ from Tukey's test.

Table 4 summarizes the children's taste sensitivity and liking for each basic taste, as measured by the different methods. Regarding taste responsiveness, the umami taste triggered the most intense sensation (mean: 53.8 mm) followed by the sweet taste (mean: 44.6 mm). Quinine showed the highest standard deviation (mean: 36.9 mm, SD = 31.8), indicating that this compound was most subject to individual variations. Further, the salty taste showed to have the lowest detection threshold level (DT_{salty} mean: 1.5, equivalent to 0.32 ± 0.20 g/L sodium chloride) followed by the sweet taste (DT_{sweet}: 1.6, i.e., 4.78 ± 2.09 g/L saccharose). Moreover, bitterness had the highest DT levels, with mean detections over Level 2 ($DT_{caffeine}$: 0.12 ± 0.07 g/L; $DT_{quinine}$: 0.002 ± 0.001 g/L). Concerning the RT level, the sweet taste showed to be the lowest (RT_{sweet} mean: 3.2, i.e., 9.81 g/L saccharose) while the bitter tastes from caffeine and quinine were the highest. Sweetness and bitterness from caffeine seemed to be the easiest tastes to name correctly once perceived, with the lowest mean differences RT-DT of 1.6 levels. On the contrary, saltiness and umami seemed to be the hardest tastes to name correctly with a mean RT-DT of 1.9 levels. In terms of concentration of the taste compounds, on average sweet was detected at a concentration of 4.78 g/L while quinine was already detected at 0.002 g/L (Table 4).

The linear mixed model of taste sensitivity showed that taste quality was the most significant factor influencing taste responsiveness and DT ($p < 0.001$), but not RT (p = 0.189). Moreover, PROP responsiveness had a significant effect on taste responsiveness (p = 0.026), but this was not observed on the DT and RT. Gender appeared to marginally influence the DT (p = 0.08), showing a higher DT for boys than girls particularly for sweetness and bitterness of both caffeine and quinine. This indicates a lower sensitivity for the sweet and bitter tastes in boys compared to girls (Figure 2).

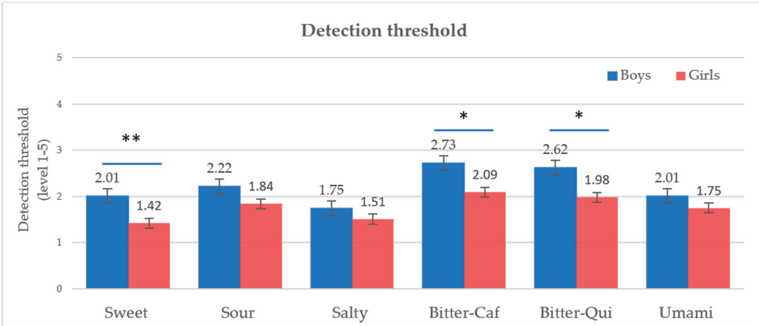
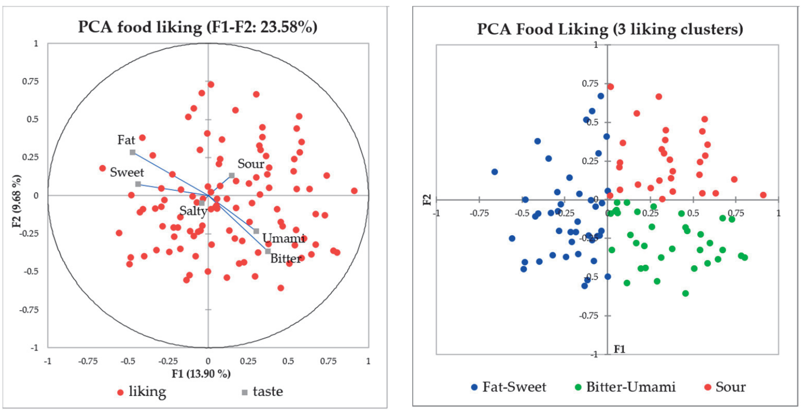


Figure 2. Detection threshold according to gender (* $p < 0.1$, ** $p < 0.05$, *t*-test).

The sensitivities to bitterness from caffeine and quinine had significant moderate correlations for responsiveness ($r = 0.47$, $p < 0.001$), DT ($r = 0.38$, $p < 0.001$), and RT ($r = 0.36$, $p < 001$). On average, there were no differences observed for DT and RT levels between these two bitter compounds. However, the children's responsiveness to bitterness was significantly higher for quinine than for caffeine (Table 4; $p = 0.006$). In addition, the liking of these two compounds was also perceived to be significantly different ($p = 0.037$). These results indicate different responses to bitterness from caffeine as compared to quinine. Finally, PROP responsiveness was not correlated with any measured bitterness sensitivity of caffeine and quinine, indicating a different bitterness sensitivity between PROP, caffeine, and quinine.

3.3. Children's Stated Food Liking

The children's reported liking of the listed food items was significantly higher for foods typical of sweet (mean liking 6.1 on a 1–7 scale) and fatty (mean = 5.9) characteristics, while foods characterized by the bitter (mean = 4.3) and umami (mean = 4.9) tastes were the least liked. The salty (mean = 5.6) and sour (mean = 5.5) foods were scored above bitter and umami foods. The children's liking score was then analyzed using a double-centered PCA. The first two principal components accounted for 23.6% of the variability. Based on the PCA, the children were divided into three groups of fat-sweet (40%, $n = 42$), sour (28%, $n = 30$), and umami-bitter (32%, $n = 34$) liking (Figure 3). Salty was neither clearly presented in the first two nor in later principal components.



(**a**) (**b**)

Figure 3. Loading from PC1–PC2 of the double-centered PCA on food liking (**a**) resulting in three taste-liking clusters of fat-sweet ($n = 42$), bitter-umami ($n = 34$), and sour ($n = 30$) likers (**b**).

The differences between the three liking clusters with respect to DT were analyzed using a two-way ANOVA. DT for the food liking clusters were significantly different for the umami taste only (Figure 4, $p = 0.024$), with the highest DT (least sensitivity) observed for the fat-sweet group and lowest for the sour group. Moreover, the bitter-umami group had higher DT for sweetness, saltiness, caffeine-bitter, and quinine-bitter compared to the other groups, but without reaching statistical significance (Figure 4). The linear mixed models showed no influence of DT and taste responsiveness on the children's food liking, the only strong effect observed was from the different taste qualities ($p < 0.001$). Moreover, neither bitterness sensitivity from caffeine nor from quinine significantly influenced the liking of the bitter foods.

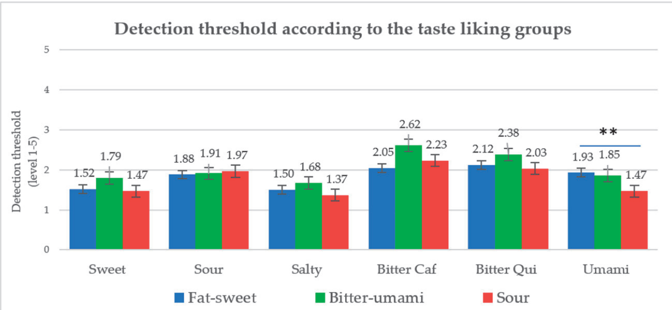


Figure 4. Mean detection threshold level for the three taste-liking groups (Caf = caffeine, Qui = quinine, ** $p < 0.05$ from ANOVA test).

3.4. Fattiness Sensitivity and Liking of Fatty Foods

Results from the pairwise milk samples comparison test (see Table 2) show that 49% of the children correctly identified the fattiest sample in the low-fat milk pair and the medium-fat pair, and 56% in the high-fat pair (Table 5). The data show that the children who were best able to distinguish the milk with the highest fat content typically preferred low-fat milk. This was observed in all pairs of the low-fat (70% of the children preferred low-fat milk), medium-fat (60%), and high-fat (61%) milk. This indicates that more fat-sensitive children tend to prefer low-fat milk samples. Moreover, in all pairs, children who were not able to differentiate the milk samples analytically tended to prefer the high-fat milk sample, indicating that non-fat-sensitive children tend to prefer high-fat milk. Further, the clusters according to the fattiness sensitivity in milk resulted in 42.5% ($n = 37$) of the children being categorized into the fat-sensitive group and 57.5% ($n = 50$) in the nonsensitive group. The ANCOVA analysis showed that the nonsensitive group had a significantly higher liking ($p = 0.04$) to fatty foods (mean liking = 6.1 ± 0.5 SD) than the fat-sensitive group (mean liking = 5.8 ± 0.8 SD). We may also note that in this analysis no effect of PROP sensitivity on the liking of fatty food was revealed.

Table 5. Fattiness sensitivity measured in milk samples ($n = 87$ subjects).

Pair	Fat Difference	Correctly Identified	Incorrectly Identified	Correctly Identified and Prefer Low-Fat Sample	Incorrectly Identified and Prefer High-Fat Sample
Low	0.5%	49% ($n = 43$)	51% ($n = 44$)	70% ($n = 30$)	68% ($n = 30$)
Medium	1.0%	49% ($n = 43$)	51% ($n = 44$)	60% ($n = 26$)	68% ($n = 30$)
High	1.5%	56% ($n = 49$)	44% ($n = 38$)	61% ($n = 30$)	74% ($n = 28$)

4. Discussion

The objective of this study was to investigate the relationships between basic tastes and fattiness sensitivity and food liking in 11-year-old children. A comprehensive approach was adopted including five basic tastes as well as fattiness, investigating bitterness through three bitter compounds, and utilizing four different methods to measure taste sensitivity in addition to fattiness. The different findings in our study are summarized in Table 6 and discussed below.

4.1. Basic Tastes Sensitivity in Children

4.1.1. Relationships between Taste Sensitivities Measured by Different Methods

In our study, we found a negative correlation between taste responsiveness and the DT and RT, while PROP responsiveness showed to be positively correlated with overall taste responsiveness (Table 6). We also found that all measured taste sensitivities were significantly correlated, except for RT and PROP responsiveness. This was true for all taste qualities. These relationships between taste sensitivities are aligned with previous investigations on adults [9,68]. In particular, Dinnella and colleagues [24] reported a positive correlation between PROP and taste responsiveness in a large population sample of adults. In our study, however, these correlations seem to be weak, corroborating previous studies [11,68,69]. This demonstrated that except for DT and RT, taste sensitivity measurements are not strongly correlated with one another as each method captures somewhat different aspects of taste sensitivity [11]. Based on our results, taste responsiveness and DT were shown to better differentiate children's taste sensitivity. It has been suggested by Fischer et al. [16] to measure directly perceived intensity for each taste, rather than using PROP responsiveness as a global indicator of taste responses.

Taste quality was the most significant factor influencing taste responsiveness and DT. However, this effect was not observed in RT. One explanation could be the number of concentration levels used. In our study, five levels were used to investigate both DT and RT. This is fewer than the eight levels used in ISO 3972 [70] for measuring basic taste recognition thresholds. However, the use of more taste levels could lead to a limitation as this practice may result in the children becoming fatigued [52]. Sensory testing with children has to be performed in the shortest possible time since they have a shorter attention span than adults [71].

Table 6. Overview of key findings across measurement approaches and taste sensations.

Variable	Methods	Tastes	Groups	Gender Effects
Sensitivity	• DT positively correlates to RT • DT and RT negatively correlate to taste responsiveness ($r = -0.14$/DT, $r = -0.11$/RT, $p < 0.01$) • PROP responsiveness positively correlates to taste responsiveness ($r = 0.13$, $p < 0.01$)	• Caffeine sensitivity correlates moderately to quinine sensitivity for DT, RT, and responsiveness, respectively ($r = 0.38$, $r = 0.36$, $r = 0.47$, $p < 0.01$) • Caffeine and quinine sensitivities (DT, RT, responsiveness) do not correlate with PROP responsiveness • Responsiveness to salty and umami, respectively ($r = 0.26$, $r = 0.24$, $p < 0.05$) have positive correlation with PROP responsiveness • Responsiveness to quinine is most subject to individual variations • Sweetness and bitterness from caffeine easiest tastes to name correctly • Saltiness and umami hardest tastes to name correctly	• PROP phenotype: 13% nontasters, 51% medium-tasters, 36% supertasters • Fat sensitivity: 42.5% fat-sensitive and 52.5% nonsensitive	Boys are marginally less sensitive than girls towards sweetness and bitterness according to DT ($p = 0.08$)
Taste liking	Taste liking does not correlate with taste sensitivity	• Fat-sensitive children prefer low-fat milk samples • Non-fat-sensitive children prefer high-fat milk samples and state higher liking of fatty foods ($p = 0.04$)	NA	Marginally higher liking score for sweet and bitter tastes ($p < 0.1$) in boys compared to girls
Food liking	Food liking poorly correlates to basic taste sensitivity measures except for Umami sensitivity (DT)	• Positively driven by sweetness and fattiness characteristics • Negatively driven by bitterness and umami characteristics	• Fat-sweet likers (40%), sour likers (28%), bitter-umami likers (32%)	No gender effect observed for food liking

DT = Detection threshold, RT = Recognition threshold, NA = Not applicable.

4.1.2. Bitterness Sensitivity to Caffeine, Quinine, and PROP

Keller and Adise [72] classified a general adult population of approximately 25% nontasters, 50% medium-tasters, and 25% supertasters. However, this general classification is highly subject to factors such as age, gender, ethnicity, and health status [72,73]. In the present study, the classification of the children's taste sensitivity based on PROP test strips led to 13% nontasters, 51% medium-tasters, and 36% supertasters (Table 6). This distribution is in accordance with a previous taste sensitivity study that reported the clusters of the taste phenotype consisting of 7% nontasters, 59% medium-tasters, and 34% supertasters in 13–17-year-old children [74]. Additionally, Mennella et al. [75] also concluded that there are age differences in PROP responsiveness, suggesting that when matched for the TAS2R38 genotype, children tend to be more sensitive than adults.

In our study, we found significant moderate correlations of bitterness sensitivity between caffeine and quinine regarding their DT, RT, and responsiveness, while no correlation was found between the bitterness sensitivity of caffeine or quinine with PROP responsiveness (Table 6). This demonstrates individual differences for bitterness as previously investigated in adults [54,55]. In these previous studies, the bitterness profiles of caffeine and quinine formed the same cluster, while the bitterness of PROP did not cluster with any other bitter compound [54]. Moreover, responsiveness to bitterness from different bitter compounds was reported to be different across adult subjects [55], as different compounds vary in their capacity to stimulate TAS2R bitter receptors [76]. Caffeine and quinine do not activate the TAS2R38 bitter taste receptor like PROP does [77,78], which indicates no genetic correlation between the bitterness perception of quinine or caffeine with PROP. This fact underlines the prevalence of individual differences for bitterness sensitivity to these compounds. Further, our results highlighted intraindividual differences in the responsiveness to and liking for caffeine as compared to quinine. Indeed, using the time-intensity method, Jane and Noble [79] compared caffeine and quinine and showed that caffeine had a longer bitter aftertaste and elicited a faster rate for maximum bitter perception than quinine, indicating different bitterness profiles between these two compounds. In summary, the different profiles, and mechanisms at play in the perception of caffeine, quinine, and PROP lead to both inter- and intraindividual differences and should be considered when selecting bitter compounds to represent bitterness in sensory studies.

4.1.3. Gender Effect on Taste Sensitivity

In our study, gender was shown to influence the children's DT, indicating a lower taste sensitivity for boys than girls, with the most evident differences observed in sweetness and bitterness (Table 6). However, gender did not affect taste responsiveness. The differences in taste sensitivity between genders remain controversial [80]. Spence [81] reported no differences between men and women in perceiving taste. It was also suggested that differences between men and women to chemosensory stimuli were due to different cognitive evaluations rather than sensory sensitivity [82]. However, our result corroborates with a previous study by Joseph and colleagues that reported significant differences in taste sensitivity based on the detection threshold in 7–14-year-old male and female subjects [7]. In this study, gender differences were reported for sweetness with lower DTs in girls compared to boys. Previous studies involving a large adult population also highlighted that women were significantly more sensitive than men for sweet, sour, salty, and bitter taste stimuli [83,84].

4.2. Children's Taste Sensitivity and Food Liking

Based on a list of 30 food items, the children showed a greater stated a liking for typically sweet and/or fatty foods than for foods characterized by other taste qualities (Table 6). This result corroborates a previous study by Dieuwerke et al. [85], which revealed that sweet and fatty tastes provide the strongest influence on food liking. Their study used tomato soups and custard samples, with varying degrees of sugar and fat. Moreover, a study involving more than 1800 children aged 6–9 years also reported that children significantly prefer sugar-sweetened apple juice and fat-enriched crackers [42].

In our study, typical bitter or umami food items were less liked than typical sweet, fatty, salty, and/or sour foods. Bitter taste triggers a rejection response in children [86] and a similar rejection was reported for umami taste in water solutions [87]. The umami taste alone (monosodium glutamate) is not palatable, therefore the children rated this taste as the most disliked in the water solution sample. However, the combination of umami with other tastes and flavors including saltiness and fattiness can create a pleasant savory perception [43]. The dislike for umami foods in our study might be due to the unfamiliarity of this taste since we record a lower familiarity for bitter and umami foods compared to other foods (Supplementary Material Table S1). Umami taste was previously categorized as an unfamiliar taste [46] and the unfamiliarity of this taste was reported to be even stronger in children aged 7–11 [45], which could explain the low acceptability of this taste.

There was no strong relationship between taste sensitivity and food liking in our study. One possible explanation is that the typical taste in food will generally lie above the detection threshold [13], while the not-so-typical, low-intensity tastes would solely be perceived by the most sensitive children. The only significant effect found was for umami sensitivity (DT) indicating that the children's taste sensitivity differed the most for this taste compared to the other basic tastes. In line with this finding, previous research has reported that individual differences in taste sensitivity vary the most for umami taste [31], as this taste has been found to have various recognition and hedonic responses [46]. Moreover, evidence for genetic variation for this taste has been revealed [88] and umami sensitivity has been reported to be significantly different in preadolescents [44].

According to Puputti et al. [89], taste sensitivity influences food consumption but there is no effect between taste sensitivity and food liking, also corroborating Tepper's study [10]. This association was investigated for the first time by Pangborn and Pecore [90] who aimed to understand the correlation between DT and hedonic response. The results showed that taste acuity stands in a different dimension from the hedonic response and these two measures may not directly explain one another. This indicates that taste sensitivity might not directly link to the food liking.

Indeed, food liking in children could not be influenced by taste sensitivity alone. Previous research has highlighted that other factors such as familiarity showed to significantly affect children's liking as children will eat what they like, and like what they know [91,92]. Extrinsic factors such as the family's socioeconomic and cultural background have been reported to also provide a significant effect on children's food liking [93]. Moreover, in our study, taste sensitivity was measured using a water solution sample, but food liking was measured by a stated liking (without tasting) in a questionnaire. This may influence the liking for each food since children have their own internal scripts and experience regarding how these foods are cooked and served [94].

4.3. Fattiness Sensitivity and Food Liking

The nonsensitive group showed to have a higher liking of fatty foods compared to the fat-sensitive group. Moreover, we also found that children who correctly identified the fatty samples in milk pairs, preferred the low-fat milk samples while the children who incorrectly identified the milk pairs preferred the high-fat milk samples (Table 6). These findings show that fattiness sensitivity influences milk preferences and significantly affects selected fatty food liking in preadolescents. The results are in line with a previous study by Bolhuis and colleagues who reported a higher acceptance for low-fat tomato soups in the fat-sensitive group compared to the nonsensitive group [95]. Similarly, Liang et al [96] underlined a higher liking for fatty foods from subjects who were not sensitive to fattiness. Furthermore, according to our results, the liking of fatty foods was not related to PROP responsiveness. This corroborates several previous studies that did not find a strong correlation between fattiness liking and PROP responsiveness [97–99].

4.4. Methodological Approach and Limitations of the Study

To our knowledge, this is the first study investigating taste sensitivity in 11-year-old children in depth, with the combination of four approaches to sensitivity measurement (detection threshold, recognition threshold, taste responsiveness, and responsiveness to PROP), the inclusion of three bitter compounds (caffeine, quinine, and PROP), and the investigation of all five basic tastes as well as fattiness in the same study. Moreover, we study relationships between sensitivity measures and taste liking in water solutions as well as food liking from a questionnaire.

The use of gamification in sensory testing has been reported to improve the participation rate of children and make them interested to join [52]. In our study, the children were excited and engaged with the sensory testing being performed as a game. This could be seen by the low dropout rate of the children as only one child was not able to finish the test despite the high number of samples that had to be evaluated (i.e., 36 water solutions and 6 milk samples in total). Moreover, the sensory testing activity was rated as fun and easy to follow by the children. The aid of technology such as the online test setup and using tablets to record the children's responses simplified the test instructions and data collection [71].

Some limitations of our approach may be noted. Our study may suffer from cross-modal correspondence effects from the symbols that we have used to mark the samples. Symbols of natural elements (a cloud, a moon, a flower, a sun, a star, and a leaf) were used to symbolize sweet, sour, salty, caffeine-bitter, quinine-bitter, and umami, respectively. The cross-modal correspondence between visual and taste stimuli has been reported to influence children's perception [100]. This effect, however, was not investigated in our study. Furthermore, taste sensitivity results are directly dependent on the concentration levels of the chosen taste compounds. We strained to develop five comparable concentration ranges across tastants based on previous literature and extensive pilot testing, yet other results may be obtained from different concentrations and different taste stimuli choices. In addition, PROP responsiveness was investigated using a paper strip while the other taste compounds were evaluated in water solution samples, and the fattiness sensitivity was measured using a food sample (milk). All these nuances may influence the children's responses due to different matrices and appearances of the taste stimuli. Finally, the fat sensitivity test was conducted after the taste sensitivity evaluation. This may result in the children becoming fatigued, possibly leading to a higher number of children categorized in the nonsensitive fat group. In addition, few pairs of milk samples were presented, and no repetition was conducted for fat sensitivity measurement, leading to a somewhat unsecure classification in fat-sensitive and nonsensitive groups, which we also consider as a limitation of our study.

5. Conclusions

This study aimed to investigate the relationship between basic tastes and fattiness sensitivity and food liking in preadolescents. The taste sensitivities measured with different methods showed to be significantly correlated to one another except between PROP responsiveness and RT. According to our results, DT and taste responsiveness were able to better differentiate children's taste sensitivity compared to RT and PROP. Boys showed to have a lower taste sensitivity than girls according to their detection threshold for sweet and bitter tastes. Interestingly, the two bitter compounds of caffeine and quinine investigated in this study showed to be only moderately correlated in sensitivity, and perceived differently in terms of responsiveness and liking. This exhibits individual differences in bitter compounds sensitivity in preadolescents, and highlights the need to carefully consider different bitter compounds for future studies in taste sensitivity. Moreover, the fattiness sensitivity showed to significantly influence the liking of fatty foods in 11-year-old children. Our results showed no significant influence of taste sensitivity on the children's food liking for the selected food items. The children's food liking was observed to be strongly driven by different taste qualities and fattiness. These results contribute to a better holistic understanding of taste and fattiness sensitivity in connection to food liking in preadolescents.

Future research may investigate the relationship between taste sensitivity and food preferences using real or model food samples. The use of real/model food is expected to improve the relevancy of studying taste perceptions instead of measuring stated liking (without tasting) and water solutions. In addition, other factors that might influence taste sensitivity in preadolescence such as food exposure also need to be considered.

Supplementary Materials: The following are available online at http://www.mdpi.com/2304-8158/9/9/1315/s1, Table S1: Food list questionnaire and percentage of children who were familiar to the foods

Author Contributions: Conceptualization, E.E., I.B., and V.L.A.; methodology, E.E., V.L.A., and I.B.; validation, E.E., V.L.A. and I.B.; investigation E.E. and V.L.A.; resources, E.E.; data curation. E.E. and I.B.; formal analysis, E.E. and I.B.; writing—original draft preparation, E.E.; writing—review and editing, E.E., I.B., and V.L.A.; Visualization, E.E.; Supervision, V.L.A. and I.B. All authors have read and agreed to the published version of the manuscript.

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Paper 3

Basic taste sensitivity, eating behaviour, and propensity of dairy foods of preadolescent children: How are they related?

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Abstract

Taste sensitivity has been reported to influence children's eating behaviour and contribute to their food preferences and intake. This study aimed to investigate the associations between taste sensitivity and eating behaviour in preadolescents. Children's taste sensitivity was measured by detection threshold with five different concentration levels of sweetness (sucrose), sourness (citric acid), saltiness (sodium chloride), bitterness (caffeine, quinine), and umami (monosodium glutamate). In addition, the child eating behaviour questionnaire (CEBQ), the food propensity questionnaire (FPQ), and the children's body weight and height were completed by the parents. Children conducted the sensory evaluation test at schools while parents completed the questionnaires online. A total of 69 child-parent dyads participated. Taste sensitivity was significantly associated with eating behaviour in food responsiveness, emotional overeating, and desire to drink. Children who were less sensitive to caffeine bitterness (higher detection threshold) had a higher food responsiveness score, while those who were less sensitive to sweetness and to caffeine bitterness had a higher emotional overeating score. In addition, children who were less sensitive to sourness and bitterness of both caffeine and quinine demonstrated to have a higher score in desire to drink. There was no association between taste sensitivity and FPQ, but significant differences were observed across children's BMI regarding their FPQ of dairy food items, indicating higher consumption of low-fat milk in the overweight/obese compared to the normal-weight subjects. There was no significant difference in taste sensitivity according to BMI. Children's eating behaviour showed to be different across BMI demonstrating a positive association between BMI and food approach, and a negative association between BMI and food avoidance. This study contributes to the preliminary understanding of the relationships between taste sensitivity and eating behaviour in preadolescents which could be used to develop effective strategies to promote healthy eating practices in children by considering their taste sensitivity.

Keywords: Detection threshold, Basic tastes, Eating behaviour, Food propensity, Dairy foods, Preadolescents, BMI

1. Introduction

Taste significantly influences children's food preference, choice, and intake (Boesveldt et al., 2018; De Cosmi, Scaglioni, & Agostoni, 2017; Nguyen, Girgis, & Robinson, 2015). Previous studies reported that children aged 11-13 years have different intensity perceptions of basic tastes (Ervina, Berget, & Almli, 2020; Overberg, Hummel, Krude, & Wiegand, 2012) which demonstrate individual differences in taste sensitivity among preadolescents. Individual differences for sweetness sensitivity based on detection threshold were observed in 7-14-year-old children (Joseph, Reed, & Mennella, 2016). Moreover, children aged 9-11 years also have different sensitivity thresholds to bitterness (Hartvig, Hausner, Wendin, & Bredie, 2014). Other basic tastes such as saltiness, sourness, and umami have been reported to be perceived differently in terms of their intensity perception by preadolescent subjects (Kildegaard, Tønning, & Thybo, 2011; Kim & Lee, 2009; Liem, 2017; Overberg et al., 2012).

The individual differences in taste sensitivity could influence food preferences, people with low sensitivity to sweetness and fattiness have been reported to prefer a higher intensity of these tastes in their foods to meet their optimum liking (Cox, Hendrie, & Carty, 2016; Papantoni, Shearrer, Sadler, Stice, & Burger, 2021). In addition, low sensitivity to a basic taste could be related to body weight (Donaldson, Bennett, Baic, & Melichar, 2009; Overberg et al., 2012). For example, children with low sensitivity to sweet taste will seek a higher intensity of sweetness (more sugar) which can result in a higher calorie intake and a possible increase in body weight (Cox et al., 2016; Donaldson et al., 2009; Papantoni et al., 2021). Moreover, obese children have been reported to have a lower sensitivity to sweet taste compared to normal-weight children (Overberg et al., 2012). On the other hand, subjects with high sensitivity to bitterness prefer food with a low concentration of this taste (Bell & Tepper, 2006; Hartvig et al., 2014), thus hindering them to consume bitter dominant foods such as vegetables (Oellingrath, Hersleth, & Svendsen, 2013). This could contribute to the insufficiency of vegetable consumption in children. Norwegian children aged 8 and 13 years were reported to have a vegetable intake below the recommended level (Hansen, Myhre, Johansen, Paulsen, & Andersen, 2016). Moreover, 11-year-old children showed to have high preferences for sugary, salty, and fatty foods (Ervina et al., 2020) which are characterized as high caloric and poorly nutritious foods (Liem & Russell, 2019). These preferences for certain foods in children could be related to their taste sensitivity and eating behaviour.

Children's taste sensitivity has been reported to be associated with their eating behaviour. A study by Farrow and Coulthard (2012) suggested that 5-year-old children with higher taste sensitivity were more susceptible to be selective eaters compared to children with low taste sensitivity. Moreover, sensitivity to sweetness and bitterness measured by detection threshold in 8-9-year-old children was demonstrated to be correlated with their food preferences and lifestyle (Rodrigues et al., 2020). The individual differences in perceiving taste at a genetic level were reported to be associated with eating behaviour (Chamoun et al., 2018; Hughes & Frazier-Wood, 2016). The genetic variation in the sweet taste receptor, T1R2, has been reported to be associated with sugar consumption, and positively correlated with the risk of dental caries. On the other hand, the bitter taste receptor, T2R38 has been shown to influence children's eating behaviour with regards to preference and intake of vegetables (Chamoun et al., 2018), suggesting that children with low bitterness sensitivity have a higher preference and intake for vegetables (Keller, Steinmann, Nurse, & Tepper, 2002; Shen, Kennedy, & Methven, 2016; Tepper, 2008).

Taste sensitivity may also be related to food exposure. A study by Vennerød, Almli, Berget, and Lien (2017) showed that pre-school children aged 4-5 years who were more sensitive to sweetness, were also less frequently exposed to sweet foods. In children aged 12-13 years a more frequent consumption of fast food was associated with decreasing sensitivity to saltiness and, as a consequence, their preference for saltier beansprout soups increased (Kim & Lee, 2009). A recent study by Mohd Nor, Houston-Price, Harvey, and Methven (2021) demonstrated that exposure to bitter vegetables in children aged 3-5 years was able to increase liking and intake of these bitter vegetables that were initially disliked. Exposure to different flavours and tastes during early childhood is associated with children's food acceptability and eating behaviour when they grow older (Nicklaus, 2016). Frequent exposures to certain basic tastes have been reviewed to be associated with increased hedonic and intensity perceptions, and this could directly influence taste satiation (Li et al., 2020). A study by Kershaw and Mattes (2018) indicated that taste exposure was more crucial than sensory sensitivity in determining food preferences and eating behaviour. Further, children aged 4-5 years who were not sensitive to PROP (6-n-propylthiouracil) bitterness (non-tasters) had a higher acceptance toward cheese and full-fat milk compared to sensitive subjects (tasters) (Keller et al., 2002). Dairy products constitute as one of the main structures in Norwegian children's diet at age 9 to 13 years (Hansen et al., 2016). This food category provides a diverse range of essential nutrients that are highly important for children's growth and development (Givens, 2020). Therefore, it is of interest to investigate the influence of children's taste sensitivity on their exposure to dairy foods.

Understanding the relationship between taste sensitivity and eating behaviour in preadolescent children will contribute to developing an appropriate strategy to promote healthy eating behaviour for this age group. This is important because preadolescence is a critical period for the development of lifelong eating habits (Gibson et al., 2012) but at the same time, this age group was also reported to be selective eaters (Houldcroft, Farrow, & Haycraft, 2014) and they may have a risk to develop childhood obesity (Boesveldt et al., 2018; Leonie et al., 2018). Good eating practices that have been built and developed in preadolescence can be sustained until adolescence and may be persistent until adulthood (Nicklaus, 2016), Therefore it is important to shape eating behaviour towards healthy food preferences at this age. To achieve this, it is important to investigate the mechanisms and determinants of child eating behaviour including the physiological aspects such as taste sensitivity. According to Nicklaus (2020), to current date, comprehensive studies regarding eating and drinking habits of preadolescent children in relation to their taste sensitivity perceptions are still limited, which suggests the need for more research to be conducted within this field.

The main objective of this study was to investigate the association between children's basic taste sensitivity and their eating behaviour. In addition, the association between basic taste sensitivity and food propensity was investigated, with particular emphasis on dairy foods. The study used two bitter compounds, caffeine and quinine, since it has been shown that preadolescent subjects have different sensitivity perceptions for different bitter taste compounds (Ervina et al., 2020; Meyerhof et al., 2010). Moreover, the relationships between taste sensitivity, eating behaviour, and children's BMI were also explored.

2. Methods

2.1. Participants

A total of 69 children (mean age 10.9 ± 0.2 years, 46.5% boys) and their parents (one parent per child) participated in the study. They were recruited from the 6th grade in two primary schools located in Ski, Nordre Follo region, in Norway. A signed informed consent both from the children and parents was required to participate in the study. In addition, the children's verbal consent was also asked at the beginning of the sensory testing. Originally 118 children were invited to the study, wherein 11 did not return the consent form, 1 returned the form but did not complete the test, and 37 children completed the test but not their parents. The children performed the basic taste sensitivity test at schools while parents completed the questionnaire regarding their child's eating behaviour and food propensity online. The participating classes received a common reward for their participation in the study, however, all the children and parents' participation were voluntary. This study has been granted approval by the Norwegian Center for Research Data (NSD) No. 715734, following the Declaration of Helsinki while the data protection has followed the General Data Protection Regulation (GDPR).

2.2. Children's basic taste sensitivity measurement

The children's taste sensitivity was measured by detection threshold. They were instructed to evaluate five different concentration levels of sucrose (sweet), citric acid (sour), sodium chloride (salty), monosodium glutamate (umami), caffeine (bitter) and quinine (bitter) dissolved in water (Table 1). The concentration of the basic taste stimulus was adapted from a study by Knof et al. (2011) and Ahrens (2015) that was previously used to measure taste sensitivity of more than 1800 participants aged 6-9 years. All the taste compounds were food grade and purchased from Merck Kga, Germany. The samples were prepared two days before the evaluation at the sensory laboratory in Nofima, Ås. The taste compounds were dissolved in tap water, placed in a disposable cup, and served to the children at around 10 ml each. Each taste compound was distinguished by different symbols, cloud (sucrose), moon (citric acid), flower (sodium chloride), sun (caffeine), star (quinine), and leaf (umami) while the different concentrations were marked by numbers from 1 (representing the lowest concentration level) to 5 (the highest concentration level). The children did not receive any information regarding the symbols, and they did not know that each series of five cups actually carried the same taste compound, or that the cup numbers corresponded to increasing concentrations. They were only informed that they would taste samples in five series of five cups marked with symbols, that different tastes could be present in any of the cups, and that the numbers on the cups indicated the order in which they should taste the samples for each series.

The children evaluated the samples in a staircase order for each series of the taste compound, starting with the lowest concentration (level 1) to the highest concentration (level 5). The children were asked "what is the taste inside this cup?" and they had to compare the sample (inside the cup) with water as a reference. They had seven options to choose from to describe the taste of each cup: "water", "sweet", "sour", "salty", "bitter", "umami", in addition to the option of "I don't know". For any symbol series and cup, the children were free to choose among these seven available options according to their perceptions. Thus, they could use the same option as many times as they wanted without limitations. It was technically possible to re-taste the previous cups of the same series (same taste compound, same symbol) but they could not re-taste samples from the previous series (different symbol). To ensure this practice, children were instructed to discard all the cups from their table after each series, so they could not interfere with the previous tasted series.

Table 1. Concentration level of taste compounds for detection threshold

Taste	Taste compound	Level 1 (g/l)	Level 2 (g/l)	Level 3 (g/l)	Level 4 (g/l)	level 5 (g/l)
Sweet	Sucrose	3.0	6.0	9.0	12.0	16.0
Sour	Citric acid	0.05	0.1	0.16	0.2	0.25
Salty	Sodium chloride	0.2	0.4	0.8	1.2	1.6
Umami	Monosodium glutamate	0.1	0.3	0.6	1.2	1.5
Bitter	Caffeine	0.05	0.1	0.15	0.2	0.27
Bitter	Quinine	0.0014	0.0017	0.0023	0.0038	0.006

The detection threshold was obtained as the level where they could start to differentiate the sample from water (Webb, Bolhuis, Cicerale, Hayes, & Keast, 2015), i.e. choose other options than "water". Note that the level in which the children either chose the options of "I don't know" or wrongly answered the actual taste quality was also recorded as their detection threshold, as we expect they perceived the sample to be different from water. The taste series were evaluated in a randomized balanced order across children. The children's responses were recorded in an online platform (EyeQuestions, Elst, The Netherlands) using a tablet. They always received a reminder on their screen to rinse their mouth with water and to eat crackers to clean their palate between tastings of each cup. The sensory evaluation was conducted in a game-like approach called "the taste detective" (Ervina et al. (2020)). The application of this game-like concept aimed to increase the participation and completion rate of the children and to create a fun and engaging test activity (Jilani, Peplies, & Buchecker, 2019; Laureati, Pagliarini, Toschi, & Monteleone, 2015).

2.3. Questionnaires to children's parents

The parents were provided a link to an online questionnaire that was sent to their email addresses. The online questionnaire consisted of three parts. The first part asked for information regarding the family profiles such as the parent's education level, the person in charge of preparing meals at home (mother, father, mother and father, others, buy/take-away), frequency of eating together with the family at each mealtime (breakfast, lunch, dinner, and evening meal), and frequency of the children having snacks or sweets per week. These responses were recorded in a frequency score option of 1= "never/rarely", 2= "1-3 times per week", 3= "4-6 times per week", and 4= "everyday". In addition, parents reported the weight (in kg) and height (in cm) of their child that was then used to calculate the child's BMI. The second part of the questionnaire consisted in the Child Eating Behaviour Questionnaire (CEBQ), while the Food Propensity Questionnaire (FPQ) was completed in the third part. It required approximately 30-35 minutes for the parents for completing the questionnaires.

2.3.1 Child eating behaviour questionnaire (CEBQ)

The CEBQ was borrowed from a study by Wardle, Guthrie, Sanderson, and Rapoport (2001) and includes 35 statements categorized into 8 different dimensions to measure children's eating behaviour. The dimensions consist of food responsiveness (5 items), enjoyment of food (4), emotional overeating (4), desire to drink (3), satiety responsiveness (5), slowness in eating

(4), emotional undereating (4), and food fussiness (6). The eight domains of the CEBQ assessed two global response patterns to foods known as "food approach" (includes food responsiveness, emotional overeating, enjoyment of food, desire to drink) and "food avoidance" (satiety responsiveness, slowness in eating, emotional undereating, food fussiness) (Vandeweghe, Vervoort, Verbeken, Moens, & Braet, 2016). The complete explanation of each dimension in CEBQ has been previously reviewed (Freitas, Albuquerque, Silva, & Oliveira, 2018).

The parent's responses to the CEBQ were recorded in a five-point agreement scale ranging from 1= "completely disagree", 2= "disagree", 3= "neither agree nor disagree", 4= "agree", and 5= "completely agree" (Wardle et al., 2001). The questionnaire was translated from English to Norwegian, then back translated for validation and adjustments by the research team and colleagues at the department, in Nofima, Ås. The CEBQ has good reliability and validity to evaluate eating behaviour in children aged 5-6 years (Quah et al., 2019), 5-12 years (Njardvik, Klar, & Thorsdottir, 2018), and 7-12 years (Tay et al., 2016). Moreover, the CEBQ has been applied in different countries (Santos et al., 2011; Sleddens, Kremers, & Thijs, 2008; Tay et al., 2016), and the results indicated that CEBQ is a good instrument to evaluate eating behaviour in children (Freitas et al., 2018).

2.3.2 The food propensity questionnaire (FPQ)

The FPQ was completed by the parents and aims to measure how often the children ate the selected food items. The questionnaire consisted of nine different food categories involving 81 selected food items such as 1) starchy foods (bread, pasta, rice, and potatoes), 2) spreads, toppings, and sandwich fillings, 3) breakfast cereals, 4) dairy products, 5) meat, fish, seafoods, soups, 6) vegetables, 7) fruits and berries, 8) desserts, cake, snacks, and sweets, and 9) drinks. The dairy products consisted of 14 items: brown whey cheese, semi-hard cheese, spreadable cheese, parmesan, butter, whole milk, low-fat milk, skimmed milk, fermented milk, chocolate/strawberry-flavoured milk, plain yogurt, fruit yogurt, ice cream, and dairy pudding. The focus is brought on the dairy category in the present study because a previous study reported a significant contribution of dairy foods in Norwegian children's daily intake (Hansen et al., 2016). The FPQ questionnaire was adapted from a previous Norwegian dietary survey by Totland et al. (2012). The food items were then further categorized according to their basic taste profiles into sweet, sour, salty, bitter, and umami foods. The categorization follows a study by Martin, Visalli, Lange, Schlich, and Issanchou (2014) who developed a food taste database of nearly 600 food items based on a Spectrum^{TM}-like profiling approach by trained panellists. The parent's responses regarding how often their child eats these selections of foods were recorded in a six-point scale of eating frequency ranging from 1= "never/rarely", 2= "1-3 times per month", 3= "1-3 times per week", 4= "4-6 times per week", 5= "daily", and 6= "more than once a day". The list of food items was presented and evaluated in a random order within categories across parents.

2.4. Data analysis

The children's BMI was calculated from the weight (kg) and height (cm) reported by the parents. The classification for the weight status into obesity, overweight, normal, and underweight groups followed the BMI/age chart standard for school-age children based on WHO (2007). In the present paper, the classification of children according to their weight status will be divided into two groups, the normal weight group consisting of underweight and normal BMI, whereas the overweight and obese subjects were merged into an overweight/obese group. Parent's education, responsible person for preparing meals at home, frequency of eating together in the family, and frequency of eating snacks or sweets of the children were analysed descriptively.

The association between taste sensitivity and eating behaviour was investigated using linear regression with the CEBQ score as the response variable and detection threshold of the six different taste compounds employed as the explanatory variables. The models were computed for each CEBQ domain and each taste compound separately (8 CEBQ domains and 6 taste compounds).

The FPQ score of eating frequency for each food item was converted into Daily Frequency Equivalence (DFE) following a study by Laureati et al. (2020). The score was computed by converting the eating frequency scale proportionally into 1 equivalence a day (the score of DFE= 1, meaning that the food item was consumed daily). The DFE score for eating frequency in the present study became as follows: DFE 0 = never/rarely, 0.07= 1-3 times/month, 0.25 = 1-3 times/week, 1 = daily, 2= more than once a day. The relationship between taste sensitivity and food propensity was analysed using a mixed model ANOVA with FPQ score (DFE) as a response variable. The detection threshold level and different taste quality of sweet, sour, salty, bitter-caffeine, and umami were employed as explanatory variables. In this model, the interaction between the detection threshold and taste quality was included and children was involved as random effect. The restricted maximum likelihood (REML) method was applied for fitting the model. To further investigate the effect of FPQ per food taste (i.e., sweet foods, sour foods, salty foods, etc.), five linear regression models were computed with taste detection threshold as explanatory variable and FPQ scores per food as response variables. The detection threshold of caffeine was chosen to represent the bitterness sensitivity as this compound has more commonly been used in taste sensitivity and dietary studies than quinine (Ahrens, 2015; James, Laing, & Oram, 1997; Puputti, Aisala, Hoppu, & Sandell, 2019; Rodrigues et al., 2020). Moreover, caffeine is used as the standard for measuring the bitterness sensitivity according to the international standardisation organization, ISO (2011).

The association between FPQ for dairy products and taste sensitivity was also evaluated using mixed model ANOVA. The FPQ score was employed as response variable while the detection threshold, dairy food items, and BMI were involved as explanatory variables. The models were computed separately for each basic taste and children nested within BMI was involved as a random effect. The significant differences across different BMI status (normal/underweight vs. overweight/obese) for each dairy food item was further computed using student t-test.

The association between taste sensitivity and BMI was investigated using linear regression models. The models were computed separately for each taste compound (sweet, sour, salty, bitter-caffeine, bitter-quinine, umami) as explanatory variables, BMI score was employed as a response variable, and gender as a control variable. Principal Component Analysis (PCA) was applied to map the associations between CEBQ, taste detection threshold, and BMI. The PCA was computed with children as rows and CEBQ (per domain) as columns, BMI and detection threshold were involved as supplementary variables. The significant differences between BMI groups of each eating behaviour domain were computed using a student t-test. All data were analysed using the XLSTAT Sensory version 2020.3.1 (Addinsoft, Paris, France).

3. Results

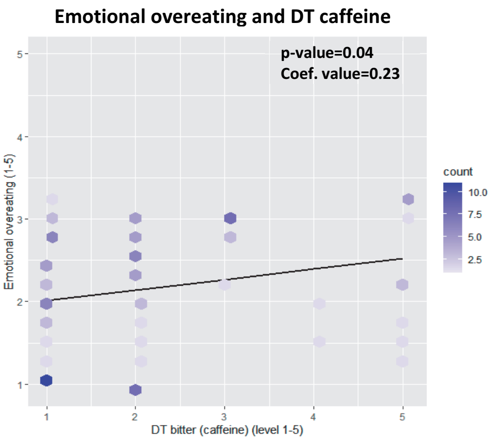
3.1. Family eating habits and children's BMI distribution

Most of the parents who participated in this study have a university degree (at least Bachelor's) as their highest level of education (79%). Mothers were most frequently responsible for cooking at home (55%) while fathers alone accounted for only 10%. Shared meal responsibility (mother and father) applied in 33% of the homes. Most of the children ate dinner together with their parents almost every day (93%), quite often for breakfast (46%) but less often for lunch (10%). In addition, more than 90% of the parents gave their child snacks or sweets 1-3 times per week.

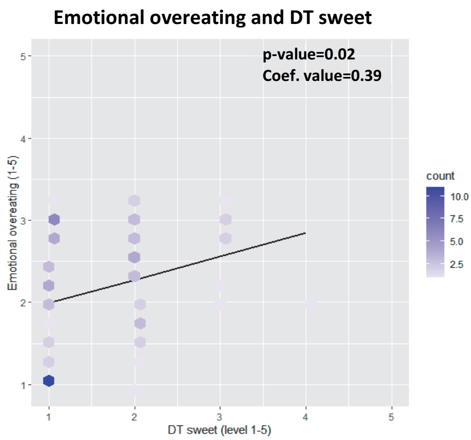
Based on the computed BMI, most of the children were categorized to have a normal weight status (68%, n=46, 47%% boys), followed by overweight (28%, n=19, 50% boys), obese (4%, n=3, 33% boys), and one child was categorized as underweight (1%, n=1). The gender distribution was quite balanced across the BMI groups.

3.2. Children's taste sensitivity and eating behaviour

The children's taste detection threshold (DT) was positively associated with some aspects of their eating behaviour, the effect size was, however, small with regression coefficients in the range 0.19 to 0.39 (Figure 1). A significant and positive association was found between food responsiveness and threshold for bitter caffeine (p=0.04). Children who were less sensitive (higher detection threshold), to caffeine bitterness had a higher food responsiveness score which indicates that these subjects tend to overeat. In addition, children less sensitive to sweetness (p=0.02) and caffeine bitterness (p=0.04), also have a significantly higher score for emotional overeating. Significant and positive associations were also found in sourness (p=0.04), bitterness of caffeine (p<0.01) and quinine (p=0.03) towards the desire to drink, demonstrating that children who were less sensitive to these tastes have a higher score for desire to drink.



(a)



(b)

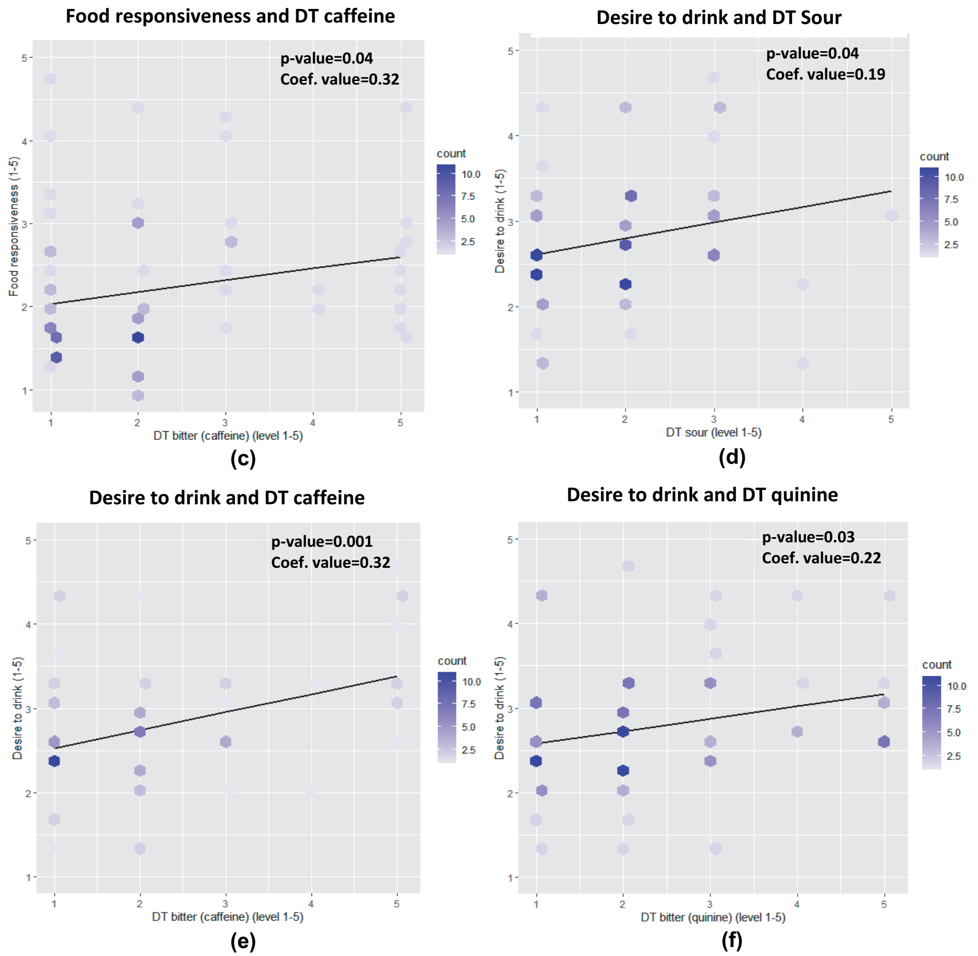


Figure 1. The associations between children's taste sensitivity and eating behaviour for emotional overeating (a, b), food responsiveness (c), and desire to drink (d, e, f) (DT= detection threshold)

3.3. Relationships between eating behaviour (CEBQ), food propensity (FPQ), and weight status (BMI)

The Cronbach's alpha of CEBQ showed a good internal consistency for both food approach and food avoidance (Cronbach's alpha= 0.84 and 0.75, respectively) and each of the CEBQ domains also showed a good internal consistency (all Cronbach's alpha ≥ 0.75) except for food fussiness and desire to drink (0.63 and 0.66, respectively). The PCA analysis showed that food responsiveness, emotional overeating, desire to drink, and enjoyment of food were positively associated with the children's BMI (Figure 2). In contrast, satiety responsiveness, slowness in eating, and food fussiness were associated with lower BMI on factor 1. The student t-test comparing the two groups (normal and overweight/obese) for each eating behaviour domain demonstrated a significantly higher score ($p \leq 0.05$) for overweight/obese children in emotional overeating and food responsiveness. Moreover, normal weight subjects have a significantly higher score ($p \leq 0.05$) in satiety responsiveness and slowness in eating compared to the overweight/obese subjects. The PCA biplot (Figure 2) also displays positive associations between BMI and detection thresholds, where the detection thresholds were included as supplementary variables.

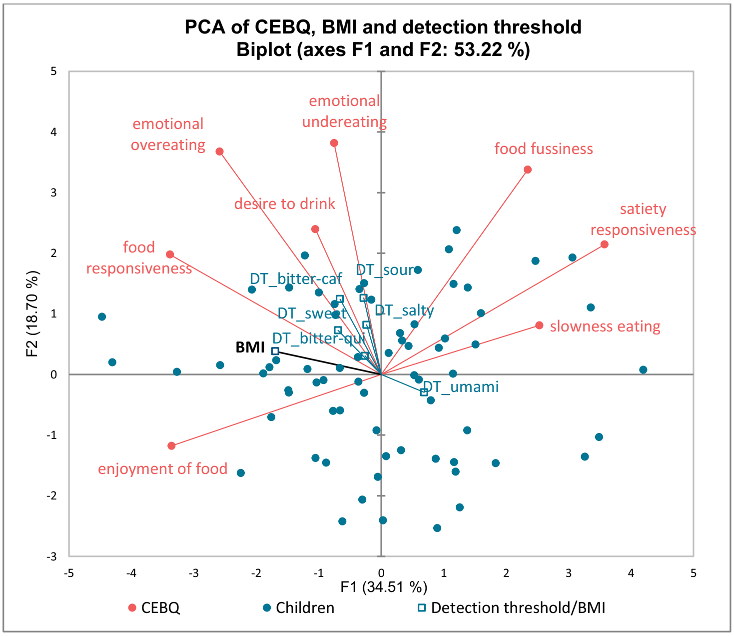


Figure 2. PCA biplot of CEBQ, detection thresholds, and BMI (DT=detection threshold)

Based on linear regression, our results did not show a significant influence of taste sensitivity on children's BMI. Neither could we detect any significant effect of children's basic taste sensitivity on FPQ score in general, showing that taste sensitivity threshold did not relate to frequency consumption of certain foods. However, when the BMI variable was involved in the model, there were significant differences in the FPQ for the selected dairy products between the normal weight and overweight/obese children. These differences were significant for semi-hard cheese ($p=0.08$), fermented milk ($p=0.02$), skimmed milk ($p=0.03$), and chocolate/strawberry flavoured milk ($p \leq 0.01$) showing that normal weight subjects frequently consumed these dairy food items compared to overweight/obese (Figure 3). Moreover, there was a tendency for the overweight/obese group to consume more low-fat milk (0.5-1.8% fat) compared to the normal weight group ($p=0.1$).

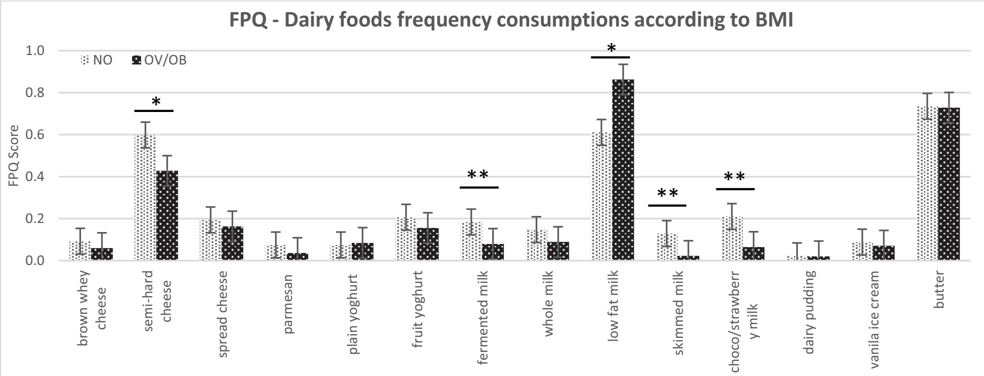


Figure 3. The food frequency consumption (FPQ) of dairy food items according to children's BMI (NO=normal weight children, OV/OB=overweight/obese children), *p≤0.1, **p≤0.05 based on mean value on student t-test

4. Discussion

4.1. Children's BMI

According to the Norwegian Institute of Public Health (2018), the prevalence for overweight and obesity in 9-year-old children was recorded to be 18% and 3%, respectively, where girls have a slightly higher prevalence of overweight (19%). These numbers corroborate a previous study by Juliusson et al. (2010) who calculated the overweight and obesity prevalence with more than 6000 Norwegian school children from 2-19 years old. Their research highlighted a higher prevalence of overweight and/or obesity in children aged 6-11 years (17%) than in younger children aged 2-5 years (12.7%) and the risk was increased with lower parental education. Our results showed a higher number for overweight (28%) compared to the literature. This could be due to erroneous data from parents since the BMI data were not collected by direct anthropometry measurement and could also be an artefact of our small sample size or reflect regional differences. Despite the increase in prevalence of obesity in Europe, Norway was able to keep the obesity rate lower compared to other European countries. A recent study comparing obesity prevalence in Europe in primary school children demonstrated that overweight, obesity, and severe obesity prevalence vary greatly across Europe with the highest value recorded in southern Europe (Greece and Spain, total prevalence 42-47%) while northern Europe have lower prevalence (Norway, Sweden, 23-25%) (Spinelli et al., 2019).

4.2. Associations between children's basic taste sensitivity and eating behaviour

The results showed that children who were less sensitive to caffeine bitterness have a higher food responsiveness score. Bitter taste is commonly associated with food aversion (Reed & Knaapila, 2010; Reed, Tanaka, & McDaniel, 2006) and this taste acts as a "barrier" for humans not to ingest poisonous foods (Mennella & Bobowski, 2015) since bitter taste is biologically linked with poisonous substances (Reed & Knaapila, 2010). The higher food responsiveness score reflects a higher appetite and an increased desire to eat (French, Epstein, Jeffery, Blundell, & Wardle, 2012). The association between low sensitivity to bitterness and higher food responsiveness could be explained by the loosening "barrier" of bitter taste that may be triggering children to eat more food types, and therefore more food in general. A study by Goldstein, Daun, and Tepper (2007) also provides a similar result with our study showing that 9-year-old children who were less sensitive to bitterness of PROP had a higher daily energy intake compared to children who were sensitive to bitterness. This result shows an association between bitter sensitivity and food intake that could correspond to food responsiveness in CEBQ.

Emotional overeating in CEBQ represents an increase in food intake as a response to negative emotions such as anxiety, anger, and boredom (Freitas et al., 2018). Our results show that children who were less sensitive to sweetness and bitterness of caffeine have a higher emotional overeating score. This could increase their food intake when they experience negative emotions. Comfort foods such as sweet and fatty foods have been reported to be typically consumed in the presence of negative emotions (Jacques et al., 2019; Michels et al., 2012; Pilska & Nesterowicz, 2016; van Strien et al., 2013). Negative emotions can modulate desire to eat (Macht, 2008) and subjects with emotional eating attitudes have learned to cope with their negative feelings by eating comfort foods as a way to find satisfaction (Adam & Epel, 2007; Macht, 2008; Michels et al., 2012). Michels et al. (2012) also conclude that eating triggered by negative emotions in children aged 5-12 years was positively correlated with their sweet food consumption. In addition, Ashi et al. (2017) reported that children aged 13-15 years who were less sensitive to sweetness had a significantly higher intake for sweet foods. These could support the association between sweet taste sensitivity and emotional overeating behaviour found in our study. Further, several studies have suggested that low sensitivity to bitterness could increase children's food intake (Goldstein et al., 2007; Keller & Adise, 2016; Tepper, Neilland, Ullrich, Koelliker, & Belzer, 2011). Previous studies also report that food intake in children could be modulated by negative emotions (Hill, Moss, Sykes-Muskett, Conner, & O'Connor, 2018; Macht, 2008; Michels et al., 2012). These could explain the relationships found between sensitivity to bitterness and emotional overeating in this study.

Our results also show that taste sensitivity for sourness and bitterness (both caffeine and quinine) were significantly associated with desire to drink. The CEBQ domain for desire to drink aimed to identify children's desire for drinking, in particular for sweetened beverages and this domain has previously been associated with food approach (Freitas et al., 2018; Quah et al., 2019; Sweetman, Wardle, & Cooke, 2008; Vandeweghe et al., 2016; Wardle et al., 2001). Our result corroborates with a previous study by Mennella, Pepino, and Reed (2005) which demonstrated that 5-10-year-old children who were not sensitive to PROP bitterness had heightened preferences for sweet beverages and soft drinks, and preferred more sugar added in their cereals and beverages. Interestingly, the sourness perception and thirst regulation occurred via the same acid-sensing receptor cell, which is called polycystic kidney disease 2-like 1 (PKD2L1) (Bichet, 2018; Gravina, Yep, & Khan, 2013). A study by Zocchi, Wennemuth, and Oka (2017) also revealed that mice without PKD2L1 showed a total loss in water and acid responses indicating that this receptor plays an important role in both water and sourness perceptions. This suggests that the activation in the receptor cell PKD2L1 due to sourness perception could modulate desire to drink. The involvement of the same receptor in the molecular mechanism of perception could be a potential underlying reason for the significant relationship found between sourness sensitivity and desire to drink in this study.

4.3. Caffeine and quinine sensitivities and eating behaviour

In our study, children's food responsiveness and emotional overeating were associated with sensitivity to caffeine bitterness but not to quinine bitterness. Preadolescent children demonstrated individual differences in the perception of different bitter compounds such as caffeine and quinine, as was reported in a previous paper using data from the same participants (Ervina et al., 2020). The different bitter taste compounds have different bitterness profiles, and they elicit various intensity perceptions of bitterness (Kamerud & Delwiche, 2007; Yokomukai, Cowart, & Beauchamp, 1993). Compared to the other four basic tastes, bitter taste has the largest and the most varied compounds with more than 25 bitterness receptors responsible for bitter taste perceptions in humans (Meyerhof et al., 2010; Roura et al., 2015). Caffeine and quinine may not activate the same bitterness receptors, and this could result in differences in bitterness perception (Kamerud & Delwiche, 2007). Moreover, these two bitter compounds are not comprised in the same foods, which may also explain the different relationships between bitterness in quinine and caffeine and eating behaviour in children.

Eating behaviour is influenced by many factors (DeCosta, Moller, Frost, & Olsen, 2017; Scaglioni et al., 2018) such as parental feeding practices, family environments, parents' education and economic condition, the obesogenic environment, and media exposure. Our results indicate that taste sensitivity also modulates eating behaviour in preadolescents.

4.4. Relationship between basic taste sensitivity and FPQ

According to our results, no significant associations were found between taste detection threshold and FPQ score for any of the five taste modalities. Further analyses did not show any systematic relationships between detection thresholds and food propensity for a given taste (i.e., between sweet threshold and sweet foods, salty threshold with salty foods, etc.). These results indicate that basic taste sensitivity did not systematically relate to the eating frequency of foods with the same dominant basic taste.

Parents of preadolescents still act as the primary food providers at home and have control over their child's eating practices (Houldcroft, Farrow, & Haycraft, 2016). Moreover, preadolescents have been characterized as curious and autonomous eaters, but their drinking and eating habits are still framed by their parental food practices (Nicklaus, 2020). The children's eating frequency recorded by FPQ may, however, not capture what is children's "actual" consumption but rather indicate what is "served" to them by their parents. FQP filled in by parents will for instance not reflect food that is consumed without parental supervision (i.e., eating outside home). In the USA, as many as 35% of children in early adolescence have been reported to eat outside home, with a big contribution of fast food (Reicks et al., 2015). The FQP may therefore have low precision when it comes to revealing possible relations between food frequency and taste sensitivity. Differences between reports by parents and children could be of interest for follow-up studies. Further studies on relations between taste sensitivity and food propensity should both involve a more complete FPQ, as well as a larger number of subjects.

4.5. Association between dairy food propensity and children's BMI

There were significant differences in the frequency consumption of dairy foods across different BMIs. The differences were significant in fermented milk, skimmed milk, and flavoured milk (chocolate/strawberry milk). Low-fat milk is the only dairy food that was consumed more frequently by the overweight/obese group while the other dairy foods (semi-hard cheese, fermented milk, skimmed milk, and flavoured milk) were consumed more frequently by normal-weight children or consumed in nearly equal frequency between the groups (for example in butter and cheese spread).

The Norwegian legislation (2015) classifies pasteurized milk into three categories according to fat content; full fat milk (≥ 3.5% fat), low-fat milk (0.5-1.8% fat), and skimmed milk (< 0.5% fat). The Norwegian Directorate of Health (2016) recommends low-fat milk for regular consumption. Milk is a standard lunch drink in Norway, and it is therefore also recommended that schools in Norway only serve drinking milk with ≤ 0.7% fat content (low-fat). This could explain the higher consumption of low-fat milk compared to whole milk or skimmed milk in our results. Moreover, the higher consumption of low-fat milk in the overweight/obese group probably appears because parents choose dairy milk products with lower fat content when they realize their child is overweight/obese, especially as almost 80% of the parents in this study had a high education level (bachelor's degree or higher). This could also be the reason for the lower cheese and flavoured milk consumption in overweight/obese children since these products have a high fat or sugar content. Parental education level has been reported to be positively associated with diet quality of children aged 10-11 years (Cribb, Jones, Rogers, Ness, & Emmett, 2011; van Ansem, Schrijvers, Rodenburg, & van de Mheen, 2014). These diets are characterized by a lower intake in sugar and fat (Fernandez-Alvira et al., 2013). Moreover, in the obesogenic environment, control and monitoring of children's food environment and intake by parents were essential to reduce children's weight status to be close to normal weight (Gahagan, 2012). In addition, a recent systematic and meta-analysis review by Vanderhout et al. (2020) suggested that higher consumption of whole milk is associated with low adiposity in childhood which could be related to the results found in our study.

4.6. Relationships between children's basic taste sensitivity, BMI, and eating behaviour

Our results did not show a significant association between taste sensitivity and BMI in preadolescents. However, previous studies suggest that overweight and obese children have a lower taste sensitivity (Cox et al., 2016; Overberg et al., 2012; Papantoni et al., 2021; Rodrigues et al., 2020). The reason we could not find a relationship between taste sensitivity and BMI could be due to our small data set and the unbalanced number of children between the BMI groups (70% normal weight and 30% overweight/obese). However, Cox et al. (2016) reported that the relationship between taste sensitivity and weight in children is still debatable and requires more evidence. A recent study investigating taste sensitivity and BMI in children aged 7-12 years concluded with no significant differences for sweetness and bitterness sensitivity between the normal-weight and overweight groups (Lim et al., 2021). A similar result was also reported by Alexy et al. (2011) in a study involving a large sample set of 574 children and adolescents aged 10-17 years. Their study concluded that there was no significant difference in basic taste sensitivity across different BMIs. Other factors than taste sensitivity such as food preferences, parental feeding practices, genetic factors, obesogenic environment, and family social economic status have been reported to play significant roles in the determination of children's BMI (Donaldson et al., 2009; Leonie et al., 2018; Lytle, 2009; Scaglioni et al., 2018; Woo Baidal et al., 2016).

Correlations were found between children's BMI and their eating behaviour based on the PCA mapping. The results indicated that the food approach domains such as food responsiveness, emotional overeating, desire to drink, and enjoyment of foods were positively associated with children's BMI, while food avoidance such as satiety responsiveness, slowness in eating, and food fussiness were negatively correlated with children's BMI. The differences between the BMI groups were confirmed with student t-tests. Our results corroborate previous studies that used the same CEBQ instrument (Sanchez, Weisstaub, Santos, Corvalan, & Uauy, 2016; Santos et al., 2011; Viana, Sinde, & Saxton, 2008; Webber, Hill, Saxton, Van Jaarsveld, & Wardle, 2009). These results are also in agreement with several other previous studies (French et al., 2012; Santos et al., 2011; Tay et al., 2016; Webber et al., 2009). Eating behaviour of food approach in CEBQ has previously been associated with increased BMI in children (Braet & Van Strien, 1997; Vandeweghe et al., 2016).

The PCA mapping also demonstrated that a higher detection threshold (lower taste sensitivity), may relate to a higher BMI, and this might be associated with the food-approach domain of CEBQ. Children's BMI has been reported to differ according to their taste sensitivity (Cox et al., 2016; Overberg et al., 2012; Papantoni et al., 2021) and children's eating behaviour in the food approach domain was also strongly correlated with higher BMI (Freitas et al., 2018; French et al., 2012; Quah et al., 2019; Sanchez et al., 2016). This indicates that taste sensitivity could mediate the complex interplay between eating behaviour and BMI in preadolescent children.

4.7. Study limitations

Our study involved a limited number of participants and an unbalanced number of children for each BMI group, as a result of recruitment of whole school classes. We recommend involving more participants and to have a balanced number between normal and overweight/obese subjects for future studies. One possibility could be by involving hospitals or healthcare centres which are dealing with obesity treatment in children. Moreover, the children's BMI was determined by a parent-reported questionnaire of body weight and height. An actual anthropometric measurement of children's weight and height is recommended for more precise data (Linchey, King, Thompson, & Madsen, 2019).

There was a possibility of cross-modal correspondence effect in our study between taste and visual stimuli because we were using different symbols to label different taste compounds of the samples. For example, the use of "cloud" symbol to represent sweet taste could influence children's perception due to this cross-modal effect. Spence (2011) reported that cross-modal correspondence between different sensory modalities such as between visual and taste stimuli could influence taste perception. A previous study also reports a significant association between certain symbols and specific taste of cheeses suggesting a moderate effect of cross-modal correspondence in sensory perceptions (Spence, Ngo, Percival, & Smith, 2013).

5. Conclusion

This study aimed to investigate the association between taste sensitivity and eating behaviour in preadolescents. The results indicate a positive association between higher detection threshold (lower sensitivity) and higher scores in the food approach domain of CEBQ. There was no influence of children's taste sensitivity on their food propensity. However, children differed according to their BMI for the propensity of dairy foods. Further, our results confirmed a positive relationship between children's BMI and food approach, and a negative relationship between BMI and food avoidance. To our current knowledge, this is the first study to investigate the association between taste sensitivity and eating behaviour in 11-year-old children with all basic tastes (sweetness, sourness, saltiness, bitterness, umami) and with two bitter taste compounds of caffeine and quinine employed in the study. This study contributes to understanding the association between taste sensitivity and eating behaviour of preadolescent children by considering their taste sensitivity. The results could be used as preliminary findings to design future studies involving a larger number of participants as well as other cultures.

Competing interests

No competing interests were disclosed

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Data availability

This project contains following underlying extended data that available at https://doi.org/10.5281/zenodo.5468625 titled "Taste sensitivity and eating behaviour of preadolescent children - extended data" (Ervina, 2021).

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Paper 4

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Article

Does Responsiveness to Basic Tastes Influence Preadolescents' Food Liking? Investigating Taste Responsiveness Segment on Bitter-Sour-Sweet and Salty-Umami Model Food Samples

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Abstract: The objective of this study was to investigate the relationships between taste responsiveness and food liking in preadolescents. Model food samples of grapefruit juice (GF) and vegetable broth (VB) modified with four additions of sucrose and sodium chloride, respectively, were employed. Intensity perception for sweetness, sourness, and bitterness were measured in GF while saltiness and umami were measured in VB. The children (N = 148) also completed food choice, familiarity, stated liking and neophobia questionnaires. The test was conducted at school, with instructions provided remotely via video call. Four segments were defined differing in basic taste responsiveness. Segments and sucrose concentrations significantly affected liking for GF, while no significant effect of segments and sodium chloride concentrations occurred on liking for VB. An increasing sucrose concentration was positively associated with liking for GF only in the segment with low responsiveness to bitter and sour tastes. No significant differences across segments were found for food choice, familiarity, stated liking, and neophobia. Conclusively, relationships between taste responsiveness and liking are product and basic taste-dependent in addition to being subject-dependent. Strategies to improve acceptance by using sucrose as a suppressor for warning sensations of bitterness and sourness can be more or less effective depending on individual responsiveness to the basic tastes.

Keywords: taste intensity; individual differences; food preferences; suppression; bitterness; sourness; warning sensations; remote testing; children

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1. Introduction

Taste has been shown to be the most important motive in children's food choice and acceptance, independently of age. This was reported in children aged 12–13 years [1], 4–6 years [2], and in infants less than one year old [3,4]. Taste is recognized as one of the drivers of children's food preferences and intake [5–8]. According to Reed and Knaapila [9], sweet, salty, and umami tastes could initiate liking, while in contrast bitter and sour tastes were associated with food aversion. The low intake of fruits and vegetables in preadolescent children may be related to their taste preferences, due to the presence of bitter and sour tastes in fruits and vegetables [1,10]. On the other hand, children prefer foods characterized by a high content of fat, sugar, and salt [11–13], which can contribute to increasing the risk of childhood obesity [14,15]. Sweetness is one of the basic tastes strongly associated with children's food acceptance [4,16–18] while bitterness is usually associated with food rejection since this taste is biologically linked with poisonous or toxic substances [18–20] although not all bitter compounds are toxic. Preferences for sour tastes in children provide equivocal results. Children aged 9–14 years prefer to consume fruit drinks with low sourness intensity, indicating a negative association between sour taste and children's food liking [21]. However, a previous study demonstrated that sour taste from citric acid in a water solution sample was the most liked compared to other basic tastes investigated in 11-year-old children [11].

Children's food preferences may be associated with their taste intensity perception, also known as taste responsiveness [22–25]. Taste responsiveness varies across individuals, and has been reported both in adults [26,27] and in preadolescents [11,28,29]. Individual differences in taste perception have been reported to be correlated with genetics [30–32]. PROP (6-*n*-prophylthiouracil) has been considered as a general marker for perception of a variety of chemosensory experiences [8,33]. Subjects with high intensity perception of PROP bitterness generally have heightened responses to other basic tastes as well [8,11,34]. Some of the studies did find a relationship between responsiveness to PROP and vegetable intakes such as reported by Bell and Tepper [35], indicating that 4–5-year-old children with low bitter responsiveness have a higher vegetable intake for broccoli, black olives and cucumber compared to children with high responsiveness. PROP intensity perception moderates the relationships between food consumption pattern and Body Mass Index (BMI) in 8–10-year-old children [36], where processed foods intake positively associated with body composition in non-tasters, but not in PROP-tasters. Moreover, responsiveness to bitter taste (quinine) significantly decreased the acceptance of grapefruit juice in 9–11-year-old children [28]. Inconclusive results were observed for saltiness, as Liem [37] reported that there was no strong relationship between saltiness sensitivity measured by detection threshold and preferences for salty foods in children, while Kim and Lee [38] reported that 12–13-year-old children with a higher detection threshold of saltiness have a higher liking for stew and soup. In regard to umami taste, the results from a previous study demonstrated that high umami threshold in 11-year-old children correlated to the increased of stated liking for bitter-umami foods [11]. Moreover, responsiveness to umami investigated in 13-year-old children was reported to vary according to their weight status, suggesting a relationship between umami sensitivity and children's BMI [39]. To our knowledge, studies investigating suprathreshold taste responsiveness across five basic tastes in preadolescent children are still limited, as previous research mostly focused on preschoolers [40].

Understanding factors behind food choices and preferences in relation to taste responsiveness will help in developing effective intervention strategies to promote healthy eating in preadolescent children. This is especially relevant because childhood is a critical period for the development of obesity [41]. Moreover, this age group was reported to be at risk of becoming picky eaters [42,43]. A healthy food choice and eating behavior developed during childhood will remain until adulthood [44], so it is important to build healthy eating practices that can be pursued across the lifespan.

Individual variation in taste responsiveness can be investigated using taste stimuli diluted in water solutions [11,45,46] or in model foods with varying concentrations of taste compounds to alter the intensity of different target tastes [12,47,48]. Model foods were suggested for the study of taste sensitivity perception instead of water solutions since they are more representative of real food [49]. Responsiveness and preferences to sweet taste have been previously measured in children aged 5–10 years using model pudding varied with sucrose concentrations [48]. Other model foods such as crackers, broth, beverages, or soups, varied with different target taste compounds, have been previously used to study children's taste sensitivity and preferences [12,13,16,50]. However, a study reported by Samant and Chapko [51] suggests that the use of a single tastant in water solution can minimize cross-modal interactions and/or product information effects.

The main objective of this study was to investigate the relationship between taste responsiveness and food liking in preadolescent children. Grapefruit juice and vegetable broth were used as model foods and four levels of tastant concentration were selected to induce a variation of basic tastes intensity for each series. Individual differences in the relationships between perceived taste intensity and liking in model foods were investigated, and four segments of children differing in basic taste responsiveness were identified. The relationships between children's taste responsiveness across the different segments and PROP intensity perception, food choices, stated food liking, food familiarity, and food neophobia were also explored.

2. Materials and Methods

2.1. Participants

A total of 165 seventh-grade children were invited from three primary schools located in the Nordre Follo region, in Norway. A signed written consent from the children and their parents was required to participate in the study with one school providing the consent form digitally. A total of 148 children completed the tests (mean age = 11.9 ± 0.3 years, 48% boys). The school classes were rewarded for participating in the study, though each child's participation was voluntary. Prior to the evaluation, we emphasized that the children could withdraw at any time without any consequences. The ethical approval of this study was granted by The Norwegian Center for Research Data (NSD) No. 715734 and refers to the Declaration of Helsinki of using human subjects, while data protection followed the General Data Protection Regulation (GDPR) [52].

2.2. Model Food Samples

Grapefruit juice (GF) (Cevita, Bama AS, Norway) and vegetable broth (VB) (Maggi, Nestle SA, Norway) were used as model food samples in this study. GF was selected due to the natural presence of bitterness and sourness in this product [53], which can be suppressed by the addition of sucrose [54]. VB was selected because it contains monosodium glutamate (MSG) that is perceived as umami and does not hold any meat ingredients that are avoided in some religions and personal diets. The addition of sodium chloride into the broth was aimed to elicit saltiness. Moreover, the model foods had to be easy to prepare, store, transport and serve. Four different concentrations of added sucrose (0, 40, 80, 160 g/L) were evaluated in GF and four different concentrations of added sodium chloride (0, 3, 6, 12 g/L) were evaluated in VB. The juice itself already contains natural sugars (mainly fructose) around 6.9 g/L while the broth contains around 10 g/L of salt at the base. Therefore, this resulted in a final concentration of sugar at around 6.9, 46.9, 86.9 and 166.9 g/L, respectively in GF, while salt content became 10, 13, 16 and 22 g/L in VB. However, for clarity, the concentrations in this paper were referred to the amount of tastant added into the model foods. Sweetness, bitterness, and sourness were investigated as target sensations in GF, while saltiness and umami were considered in VB. The amount of tastants to be added in each GF and VB to elicit different intensities of target tastes was selected based on a pretest with trained panelists at the University of Florence (n = 4) and Nofima (n = 11), and then with Norwegian children aged 10–13 years (n = 9).

Pre-weighed amounts of sucrose were added to the GF and stirred until completely dissolved. The GF mixture was then filtered using a sieve to remove the fruit pulp and stored in a closed container at 4 °C before being transferred into disposable cups. The VB was prepared by adding 14 g of vegetable broth powder into one liter of hot water (80 °C) and pre-weighted amounts of sodium chloride were added. The VB mixture was stirred until the broth powder and sodium chloride were completely dissolved, then filtered using a sieve to remove the small vegetable chunks. Excess fat formed at the surface of VB samples was removed using a spoon. All the food samples and taste compounds were food grade and purchased from a local supermarket. The sample preparation was conducted at the sensory laboratory at Nofima, Ås, and followed strict hygiene practices (i.e., using a mask, hand gloves, disinfecting the working surfaces, etc.).

The samples (20 mL) were served in 50 mL closed disposable cups and labeled with three-digit random codes. Each child received the samples in two boxes labeled as "box A" for liking evaluation and "box B" for taste responsiveness evaluation. Each box included four GF samples at different sucrose concentrations and four VB samples at different sodium chloride concentrations. Box A also included plain crackers for mouth rinsing

(WASA, plain, gluten free and lactose free), while a PROP paper disc was provided in box B. In addition, water and spitting cups were also provided at the children's tables. All samples were prepared one day before the evaluation, stored in a refrigerator at 4 °C overnight, and distributed to the school on the day of testing. The samples were kept at room temperature until the evaluation time, approximately 4 h from retrieval from the refrigerator.

2.3. Sensory Test Procedures: A Remote Testing Approach

The test was divided into three parts (Figure 1). In the first part, children filled in an online questionnaire on food familiarity, stated liking, and food choice of selected food items. In addition, liking data for model food samples were collected. In the second part, intensity perception responses on model foods were collected and children completed the food neophobia questionnaire. The last part aimed to measure children's responsiveness to PROP bitterness on a paper disc. Note that the children also completed personality trait questionnaires and evaluated a list of food items and the model food samples for emotional responses; these results are not reported here.

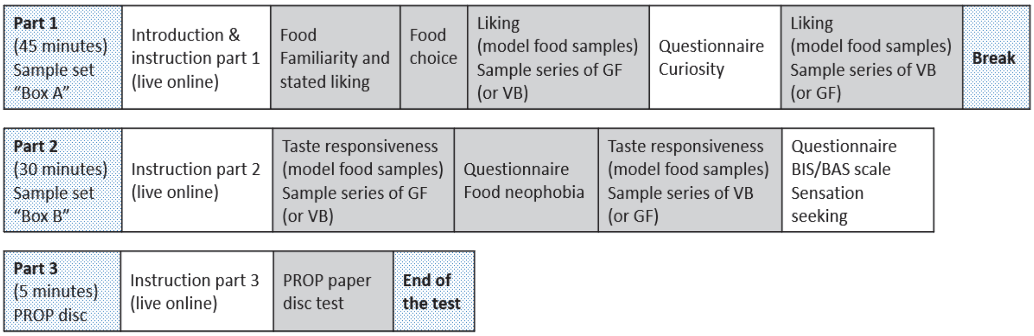


Figure 1. The study scheme (variables in grey show areas of interest reported in this paper).

All the tests were conducted at schools with one class taking the test at a time (15–22 participating children per class, 9 classes in total). Children were seated at individual tables, distanced from one another. The instructions were provided to the children at the beginning of each part (i.e., what the children should do, what samples they should taste, the explanation of the scales, etc.) with the support of a PowerPoint presentation (Microsoft Corporation, Redmond, Washington, United States). All instructions were provided via video conference call (Microsoft Teams, Microsoft Corporation, Redmond, Washington, United States) as there were restrictions in visiting the schools physically due to the Covid-19 pandemic. The video call was projected onto a large screen or smartboard in front of the class allowing the children to see and hear the instructions clearly. A video camera was turned on in the classroom during the entire evaluation, thus enabling the experimenters to monitor the test remotely. The children and teachers were able to ask questions directly to the instructor during the test and it took around two hours to finish the entire testing session (including a break). There was at least one teacher physically present in the room for the entire testing time, who assisted the experimenters with all practicalities in the classroom (i.e., placing the sample boxes on the children's table, pouring the water for each child, helping with the camera and screen setting in the class, etc.). A separate discussion with the teachers took place before the evaluation day to inform them about the whole testing procedures, timing, and to ensure that good sensory practices would be followed during the test.

2.4. Food Familiarity and Stated Food Liking

Children rated familiarity and stated liking for 28 food items categorized as fruits (10), vegetables (10), juices and desserts (8) (Supplementary Materials Table S1). Vegetable items were selected among those regularly consumed by adolescents across Europe [55]. Fruits, juices, and desserts were selected to represent options differing in sweet, sour, and bitter intensity according to a previous study [56]. Food familiarity was evaluated on a five-point scale including 1 = "I do not know it", 2 = "I know it, but I have never eaten this", 3 = "I have tasted it, but I rarely eat it", 4 = "I occasionally eat it", and 5 = "I regularly eat it" [57]. Children who rated low familiarity with a given food item (1 = I don't know; 2 = I know it, but I have never eaten this) were not asked to express their liking. Stated liking was measured on a seven-point hedonic scale ranging from "I dislike it very much" to "I like it very much". The average scores for familiarity (1–5) and stated liking (1–7) were computed for each child based on their responses to the 28 food items. The food items were presented in a randomized order within and across categories.

2.5. Food Choice

A forced-choice method was applied to evaluate the children's choice in 19 pairs of food items consisting of three categories of fruits (six pairs), vegetables (nine pairs), and juices and desserts (four pairs) (Supplementary Materials Table S2). The food items were paired within the same category, and they were selected to represent different intensities of bitter or sour tastes (lower vs. higher intensity) within the pair [58]. The vegetable pairs aimed to evaluate choice preference for bitter taste. For the selection of low/high bitter items in the vegetable pairs, data from a previous Check-All-That-Apply (CATA) questionnaire on 121 Italian preadolescents were used. This previous CATA questionnaire included a list of different vegetable names and four sensory descriptors: "sweet", "sour", "bitter", and "delicate". The six vegetable pairs in the present study were significantly different for bitterness citation frequency according to a Cochran's Q test conducted on the CATA data: lettuce-rucola, spinach-lettuce, rucola-spinach, carrot-squash, squash-tomato, and broccoli-green beans (Supplementary Materials Table S3). In addition, differences in sweetness citation frequency were considered in three vegetable pairs: green beans-corn, green beans-carrots, and green beans-peas, assuming that vegetables with higher sweetness citation were less bitter. The fruits, juices, and desserts pairs aimed to evaluate choice preference for bitter and sour taste. The selection of items was based on a study by Martin et al. [56] who created a food taste database of multiple foods evaluated by a trained panel. For example, the pair of apple-orange represents different sourness intensities (less sour for apple and sourer for orange). The children's task was to choose the food item that they preferred within the pair. The food pairs were evaluated in a randomized order within and across categories.

2.6. Model Food Evaluation (Liking and Taste Responsiveness)

Children's liking for the model food samples was recorded using a Labeled Affective Magnitude Scale (LAM) [59,60]. The use of the scale was explained to the children prior to the evaluation. Moreover, examples of foods that are generally liked and disliked by children were recalled by name and picture (i.e., a slice of pizza vs. broccoli) and children were asked to express their liking on the LAM. This allowed the children to have a little training and practice on how to use the scale prior to the evaluation [61].

The children's responsiveness to basic tastes in model food samples was recorded on the Labeled Magnitude Scale (LMS). The scale was labeled with intensity rating of barely detectable (1.4), weak (6.1), moderate (17.2), strong (35.4), very strong (53.3) and strongest imaginable (100) [62]. The five basic tastes qualities illustrated with pictures (i.e., sugar for sweetness, salt for saltiness, lemon for sourness, black coffee for bitterness, meat and soy sauce for umami) were recalled and explained to the children. The use of LMS was demonstrated to the children using pictures of foods with high and low intensity for the same taste quality (e.g., fresh lemon and lemonade for sourness, a spoon of salt and cheese for saltiness) [63]. The use of the scale was explained prior to the evaluation, and it was emphasized that there was no right or wrong answer in using the scale as it depends on one's own perception.

To prevent positional bias, samples were evaluated in a randomized balanced order across and within GF and VB series across the children (Figure 1). During tasting, children were instructed to take a sip of the sample, swallow or expectorate the sample, and rate their liking (Part 1, Figure 1) or the intensity of target tastes (Part 2, Figure 1). The children were instructed to rinse their mouth with water in between tastings and to eat plain crackers to clean their palate. The tasting sessions were conducted autonomously and at individual speed by following the on-screen instructions. The break ensured that all children were ready for new common instructions at the start of Part 2, while waiting time could occur before the start of Part 3.

2.7. Food Neophobia

The children's food neophobia was measured using the Italian Child Food Neophobia Scale (ICFNS), which consists of eight items (four neophobic and four neophilic statements) assessing the avoidance of trying new foods in children [64]. The scale was translated into Norwegian by a native speaker based upon its English version, then compared to the English version, the Swedish version and the original Italian version for adjustments [65]. The children's responses were recorded using a five-point-agreement scale with anchors "very false", "false", "so-so", "true" and "very true" [64]. After reversal of the neophilic statements, the neophobia score was computed by summing up all the scores across statements for each child. Food neophobia scores ranged from 8 (low food neophobia) to 40 (high food neophobia). The Norwegian version of the scale is available in Supplementary materials.

2.8. PROP (6-n-prophylthiouracil)

The responsiveness to PROP was measured using the paper disc method [66,67] and the children's responses were recorded using LMS [62]. The disc was impregnated with 50 mmol/L of PROP following a procedure from Zhao et al. [68]. Children were instructed to rinse their mouth with water before placing the PROP disc on the anterior part of their tongue (a picture with the correct position of the PROP disc on the tongue was presented to the children for guidance). Children were instructed to hold the PROP disc for 25 s in their mouth until it was completely soaked by their saliva, then take the paper out, wait for a further 20 s, and rate the bitterness that they perceived. The whole PROP disc testing process was individually guided with appropriate timers and instructions on screen. The test was allocated in the last part of the evaluation to refrain supertasters from being demotivated for further participation in the test. The PROP evaluation was performed 20 min after the model food tasting sessions to ensure that children did not have any lingering sensation from the previous samples.

2.9. Statistical Analysis

A mixed model ANOVA was applied to evaluate the effect of tastant concentration on the intensity of target sensations in model food samples. The statistical model was built separately for each taste (i.e., five models computed for sweetness, sourness, bitterness, saltiness, and umami) with taste intensity as the response variable, and concentrations (four concentrations of sucrose and sodium chloride in GF and VB, respectively) and gender as explanatory variables. The interaction between concentration and gender was also investigated, and child nested within gender was considered as a random effect (factors: concentration, gender (child), concentration $\times$ gender). The restricted maximum likelihood (REML) method was applied for fitting the model and post-hoc Tukey's HSD test was computed.

A taste score was calculated for each child by summing up the intensity rated for each basic taste at the four concentration levels (e.g., taste score of sweet = sweet intensity at 0 + 40 + 80 + 160 g/L sucrose) [46]. A Principal Component Analysis (PCA) was then computed with children as rows and taste score of each taste as columns (five columns). The first two principal components were used to group the children into four different segments [69]. The PCA based segmentation was chosen because of good interpretability of the segments and more balance in cluster sizes which was important for subsequent statistical analysis (ANOVA). This approach is also referred to as interpretation-based on segmentation, and by this method the subjects can be split into segments based on primary interest [70]. Chi-square analysis was computed to check gender distribution across segments. The effect of segments, gender, and their interaction on taste score, PROP intensity, and mean liking was assessed by two-way ANOVAs (factors: segments, gender, segment × gender).

The effect of different segments and tastant concentrations (four levels) on taste intensity was computed per taste, using mixed model ANOVAs (five models were obtained). In these models, segment, concentration and interaction between concentration and segment were employed as explanatory variables, whereas child nested within segment was included as a random effect (factors: segment (child), concentration, segment × concentrations). The effect of segment and concentration on liking for model foods was also assessed using the same model and computed separately for GF and VB liking, respectively. Post hoc tests were performed using Tukey's HSD test for pairwise comparison across concentrations within each segment.

A choice score was computed per child by summing up the total number of choices for the most sour and bitter options in each pair (choice score range: 0–19) [58]. The effect of segment and gender on food choice score was assessed using two-way ANOVA followed by post-hoc Tukey's HSD test. A two-way ANOVA was also applied to evaluate the effect of segment and gender on children's food neophobia, stated liking, and food familiarity (factors: segments, gender, segment × gender). In addition, further analyses for stated liking and familiarity as response variables were also computed using mixed model ANOVAs to investigate the effects of the different food items, segment, and gender (factors: segment, gender, food item, segment × gender, segment × food item, and food item × gender). Moreover, the correlation between children's stated liking and familiarity was computed using Pearson correlation.

In all statistical tests, a threshold of 5% was applied to establish significance of an effect. All data analyses were computed using XLSTAT sensory version 2021.1.1 (Addinsoft, Paris France).

3. Results

3.1. Taste Intensity Perception in the Model Food Samples

The perceived intensity of sweetness, sourness, bitterness in GF, and saltiness in VB significantly changed according to the increase in tastant concentrations, while there were no significant changes observed for umami in VB (Table 1). Sweetness intensity significantly increased in parallel with the increase of sucrose concentration in GF, while intensity of sour and bitter tastes decreased. Saltiness intensity significantly increased in parallel with the increase of sodium chloride concentrations in VB, while umami taste intensity did not show a significant difference ($p = 0.07$). Gender did not significantly affect the intensity ratings of any of the basic tastes in the model food samples ($p > 0.05$).

Table 1. Mean taste intensity ratings in model food samples with increasing tastant concentrations (sucrose in grapefruit juice, sodium chloride in vegetable broth).

Food Samples and Target Tastes	Sample 1 (Mean ± SD)	Sample 2 (Mean ± SD)	Sample 3 (Mean ± SD)	Sample 4 (Mean ± SD)	*p*-Value
Grapefruit juice (GF)	**GF 0 g/L**	**GF 40 g/L**	**GF 80 g/L**	**GF 160 g/L**	**across samples**
Sweetness	17.1 ± 20.0 [c]	20.9 ± 18.2 [bc]	24.9 ± 21.3 [b]	33.6 ± 26.2 [a]	F = 28.9, p **< 0.001**
Sourness	33.6 ± 26.0 [a]	28.6 ± 23.1 [b]	27.0 ± 22.5 [bc]	23.5 ± 22.0 [c]	F = 12.5, p **< 0.001**
Bitterness	43.2 ± 26.1 [a]	36.9 ± 21.6 [b]	34.4 ± 24.0 [b]	28.3 ± 22.0 [c]	F = 24.2, p **< 0.001**
Vegetable broth (VB)	**VB 0 g/L**	**VB 3 g/L**	**VB 6 g/L**	**VB 12 g/L**	**across samples**
Saltiness	27.2 ± 22.6 [c]	33.2 ± 23.5 [b]	37.6 ± 23.6 [ab]	41.1 ± 25.0 [a]	F = 23.6, p **< 0.001**
Umami	31.0 ± 22.4 [a]	35.0 ± 24.6 [a]	33.7 ± 23.7 [a]	34.7 ± 24.4 [a]	F = 2.4, $p = 0.07$

Different letters in rows indicate significant differences ($p < 0.05$) between mean values from Tukey's HSD test. Values in bold show a significant difference at $p < 0.05$.

3.2. Taste Responsiveness Segments

The PCA bi-plot on taste responsiveness scores is reported in Figure 2. The first two principal components accounted for 64% of the total variability. The first principal component (44.3% of total variance) differentiates children into high responsive subjects on the right and low responsive subjects on the left side. The second principal component (19.7% of total variance) divided the children according to taste qualities, with children more responsive to generally well-liked tastes (sweet, salty, umami) on the bottom and those more responsive to generally disliked tastes (bitter and sour) on the top of the map. From the visual characterization of the map, four segments were identified with one segment for each quadrant in the PCA biplot [69].

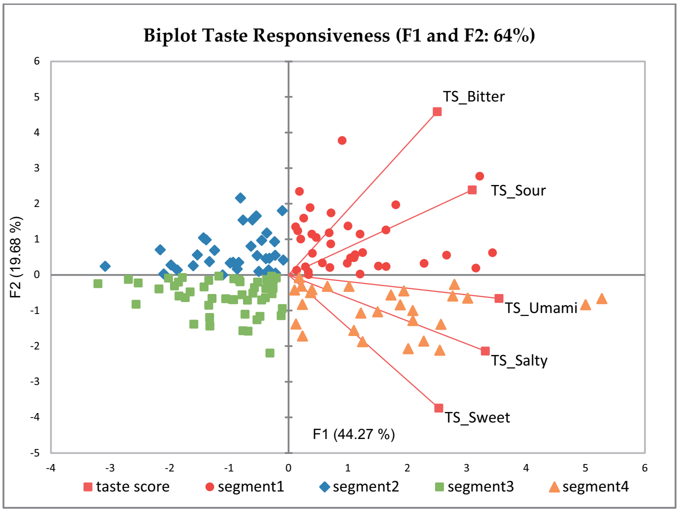


Figure 2. Children's segmentation according to taste scores. Different colors and symbols indicate different segments (TS = Taste score).

According to the two-way ANOVA, each segment was significantly different for taste score ($p < 0.001$) and no gender difference was observed across segments (Table 2). Segment 1 (S1, $n = 36$, 24%) was characterized by the children who were highly responsive to bitterness and sourness compared to the other segments, and at the same time children in this segment were also less responsive to sweetness. Segment 2 (S2, $n = 34$, 23%) was characterized by the children who were least responsive to sweetness and moderately responsive to bitterness. Segment 3 (S3, n = 50, 34%) was characterized by the children who were low responsive to all basic tastes, and they were least responsive to bitter and sour compared to the other segments. Lastly, segment 4 (S4, n = 28, 19%) was mainly characterized by the children who were highly responsive to all basic tastes and have the highest responsiveness to sweet, salty and umami tastes across the segments. The intensity perception of PROP was significantly different across segments (p = 0.01) indicating that the children who were most responsive to PROP also had high taste responsiveness to all basic tastes (S4) or highly responsive to bitter and sour tastes (S1).

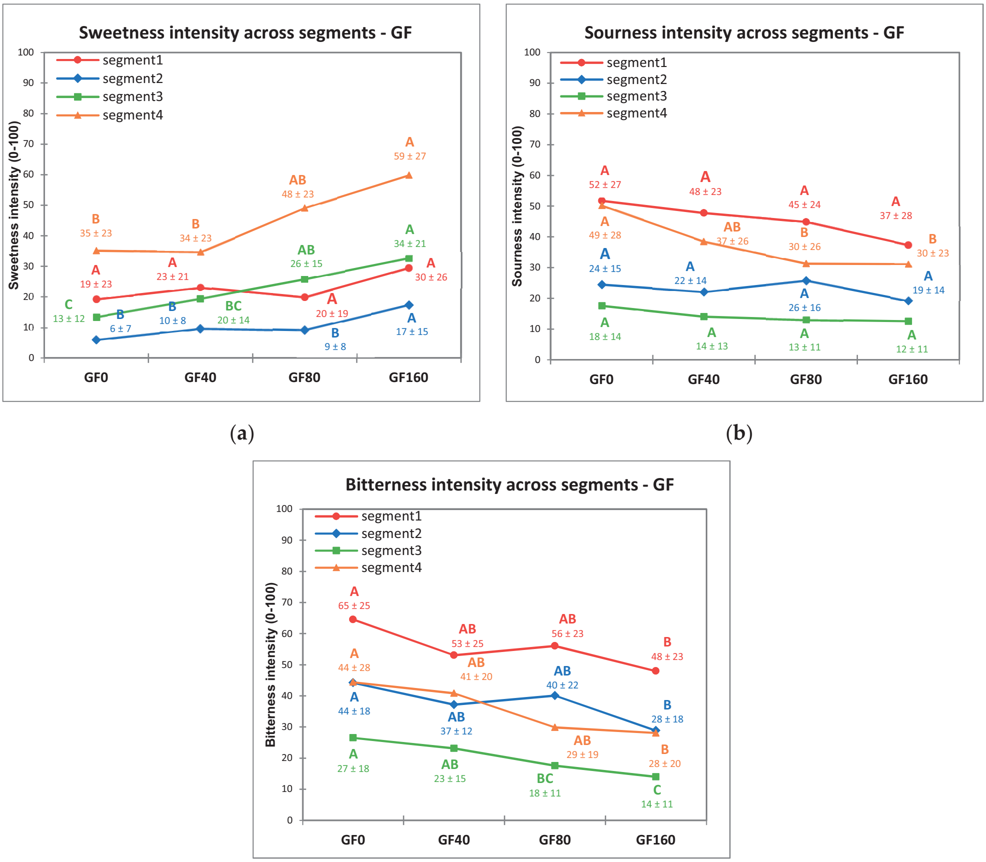
Table 2. Segment profiles according to taste score, perceived intensity, PROP intensity, and mean liking for model foods.

Variables	Segment 1 (S1) High Responsive to Bitter and Sour	Segment 2 (S2) Low Responsive to Sweet	Segment 3 (S3) Low Responsive to All Basic Tastes	Segment 4 (S4) High Responsive to All Basic Tastes	*p*-Value
All children					
(n = 148)	36 (24%)	34 (23%)	50 (34%)	28 (19%)	Chi-square,
Boys	18 (50%)	19 (56%)	18 (36%)	16 (57%)	gender
Girls	18 (50%)	15 (44%)	32 (64%)	12 (43%)	p= 0.19
Taste scores (0–400)					
Sweet (GF)	91.6 [b]	41.7 [c]	92.2 [b]	175.9 [a]	F = 36.4, $\boldsymbol{p < 0.001}$
Sour (GF)	181.6 [a]	91.3 [b]	58.1 [b]	146.7 [a]	F = 35.0, $\boldsymbol{p < 0.001}$
Bitter (GF)	221.7 [a]	149.4 [b]	81.5 [c]	141.2 [b]	F = 39.4, $\boldsymbol{p < 0.001}$
Salty (VB)	151.6 [b]	93.2 [c]	114.7 [bc]	222.3 [a]	F = 23.0, $\boldsymbol{p < 0.001}$
Umami (VB)	170.3 [b]	93.9 [c]	91.6 [c]	213.5 [a]	F = 29.6, $\boldsymbol{p < 0.001}$
PROP mean intensity (LMS 0–100)	57.4 ± 28.1 [a]	38.9 ± 28.6 [b]	39.8 ± 28.0 [b]	51.1 ± 30.0 [ab]	F = 3.52, $\boldsymbol{p = 0.01}$ gender p = 0.32
Mean liking (LAM 0–100)					
GF (mean of 4 samples)	31.1 ± 28.0 [c]	29.1 ± 22.3 [c]	45.3 ± 27.1 [b]	54.3 ± 29.0 [a]	F = 75.5, $\boldsymbol{p < 0.001}$
VB (mean of 4 samples)	30.0 ± 26.4 [b]	40.6 ± 25.7 [a]	37.5 ± 27.7 [a]	37.3 ± 31.3 [a]	F = 7.3, $\boldsymbol{p < 0.001}$

Different letters in rows indicate significant differences (p < 0.05) between mean values from Tukey's HSD test. Values in bold show a significant difference at p < 0.05. GF = Grapefruit juice, VB = Vegetable broth.

3.3. Segment Effect on Taste Intensity Perception in the Model Food Samples

The effect of segments and concentrations of sucrose (GF) or sodium chloride (VB) in model foods on perceived taste intensity was investigated separately for each basic taste using mixed model ANOVAs. The results demonstrate significant effects of segments (p < 0.001) and concentrations (sucrose/sodium chloride) for sweet (p < 0.001), sour (p < 0.001), bitter (p < 0.001), salty (p < 0.001), and umami (p = 0.03). The interactions between segments and concentrations were significant for sweet (p = 0.005) and sour (p = 0.022) tastes. The four segments showed differences in mean intensity values of target tastes based on taste scores (Table 2) and specific trends of intensity vs. tastant concentrations (Figure 3) in GF samples.

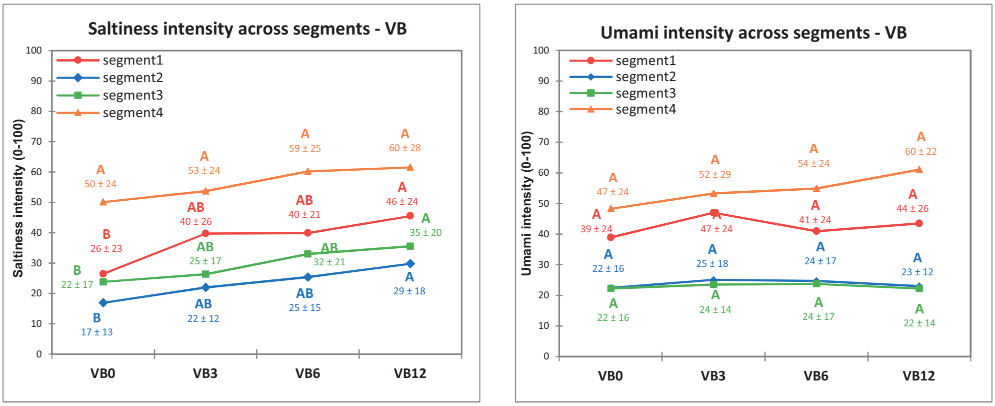


(**a**) (**b**) (**c**)

Figure 3. Taste intensity rating in grapefruit juice samples (mean intensity rating ± SD), (GF; 0–160 g/L added sucrose) for: sweetness (**a**), sourness (**b**) and bitterness (**c**) across the four segments. Different letters indicate significant differences ($p < 0.05$) from Tukey's HSD test across concentrations within each segment.

In S1, consisting of subjects highly responsive to bitterness and sourness and less responsive to sweetness, the increase of sucrose concentration in GF did not induce significant changes in neither sweetness nor sourness intensity, while only a weak but significant decrease of bitter intensity was observed. Sweetness was rated at moderate level in all samples for S1 while both bitterness and sourness were rated close to strong/very strong intensity. Thus, in this segment, sucrose addition did not significantly enhance sweetness nor suppress sourness intensity but only induced a weak suppression of bitterness. S3 was characterized by subjects with generally low responsive to all basic taste and the least responsive to both bitter and sour taste. In this segment, the increase of sucrose concentration induced a significant increase of sweetness intensity from weak to strong, associated to a significant suppression of bitterness from strong/moderate to weak, while sourness was rated as moderate/weak in all samples. S2 consisted of the children who were least responsive to sweetness. The intensity of sweetness in S2 changed from weak to weak/moderate with the increase of sucrose addition, while no significant changes were observed in sourness intensity that was rated moderate/strong in all samples, and a small but significant decrease of bitterness was observed in a range of strong/very strong intensity. Thus, in this segment, the increase of sucrose induced very small changes in sweetness, did not suppress sourness and slightly suppressed bitterness. S4 consisted of children that were highly responsive to all target tastes and showed the highest responsiveness to sweet taste; in this segment the increase of sucrose concentration induced a significant increase of sweetness intensity from strong to very strong level and a significant decrease of bitterness from very strong to strong, while sourness tended to decrease significantly at intermediate sucrose concentrations. Thus, in this segment a significant suppression of both bitterness and sourness was observed.

For the VB, segments S1, S2 and S3 had similar responses to saltiness with a significant increase in intensity response along with the increase of sodium chloride concentration, from moderate to strong in S2 and S3, and in strong/very strong range for S1, while S4 showed the same high saltiness intensity perception (very strong) in the whole sodium chloride concentrations range (Figure 4a). There were no differences for umami intensity responses across different salt concentrations in VB for any of the segments (Figure 4b). Umami intensity was of close to moderate intensity for S2 and S3, and ranged strong/very strong intensity for S1 and S4.



(**a**) (**b**)

Figure 4. Taste intensity rating in vegetable broth samples (mean intensity rating ± SD), (VB; 0–12 g/L added sodium chloride) for: saltiness (**a**) and umami (**b**) across the four segments. Different letters indicate significant differences ($p < 0.05$) from Tukey's HSD test across concentrations within each segment.

3.4. Taste Intensity Perception and Children's Liking of Model Foods

There were significant differences in mean liking for GF and VB across segments ($p < 0.001$) (Table 2). The results demonstrated that children in S1, characterized by high responsiveness to sour and bitter tastes, and S2, low responsive to sweet taste and moderately responsive to bitter taste, had a significantly lower mean liking for GF compared to the other segments. Children in S3 with generally low responsiveness to basic tastes and with the lowest bitterness and sourness responsiveness had a higher mean liking for GF samples compared to S1 and S2. S4, which consisted of the children who were highly sensitive to all basic tastes and were the most responsive to sweet taste, showed the highest mean liking for GF samples. For VB, S1 showed the lowest mean liking score compared to the other segments while there were no differences between S2, S3, and S4 (Table 2).

The differences among segments for liking in model foods was further investigated (Figure 5). There were significant effects of segment, concentration, and their interaction on the liking of GF ($p < 0.001$). Sucrose concentration positively affected liking in S3 only, showing a gradual increase of liking when the sucrose concentration is increased, while no significant changes in liking were found for other segments. There was no significant difference for liking score across the different sodium chloride concentrations in VB within each segment.

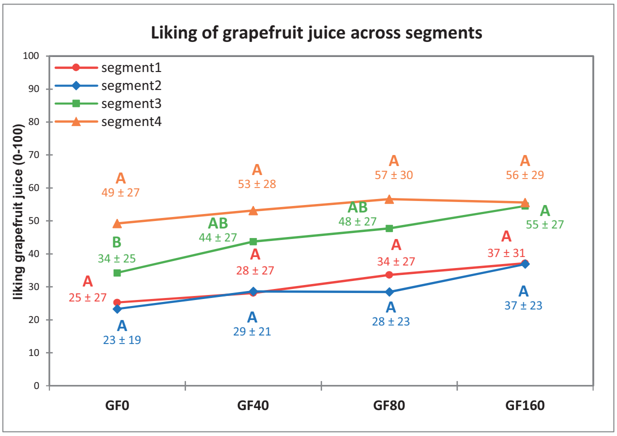


Figure 5. The effect of segment and sucrose concentration on liking for grapefruit juice (mean liking ± SD), (GF; 0–160 g/L added sucrose). Different letters indicate significant differences ($p < 0.05$) from Tukey's HSD test across concentrations within each segment.

3.5. The Relationships between Taste Responsiveness Segments, Food Choice, Stated Food Liking, Familiarity, and Food Neophobia

In the choice task, children who were highly responsive to bitter and sour tastes (S1) and those who were least responsive to sweet and moderately responsive to bitter tastes (S2) tended to have a lower choice score for sour and/or bitter food options ($p = 0.07$) (Table 3). This result indicates that these segments (S1 and S2) tended to have lower preferences towards bitter and/or sour food. There was no significant effect of segments on the stated food liking. However, the different food items were rated differently by the children ($p < 0.001$) with milk chocolate being the most liked (6.6 ± 0.7) and green beans as the most disliked item (3.6 ± 1.1).

Table 3. Mean value for choice score, stated food liking, familiarity and neophobia according to the four taste responsiveness segments.

Variables	Segment 1 (S1) High Responsive to Bitter and Sour	Segment 2 (S2) Low Responsive to Sweet	Segment 3 (S3) Low Responsive to All Basic Tastes	Segment 4 (S4) High Responsive to All Basic Tastes	*p*-Value
Choice score (0–19)	5.5 ± 2.5 [a]	5.5 ± 2.0 [a]	6.4 ± 1.9 [a]	6.6 ± 2.4 [a]	F = 2.6, $p = 0.07$ gender $p = 0.55$
Stated food liking (1–7)	5.2 ± 0.5 [a]	5.1 ± 0.6 [a]	5.3 ± 0.5 [a]	5.2 ± 0.5 [a]	$p = 0.81$ gender $p = 0.15$
Food familiarity (1–5)	3.4 ± 0.5 [a]	3.4 ± 0.4 [a]	3.5 ± 0.3 [a]	3.4 ± 0.5 [a]	$p = 0.43$ gender $\boldsymbol{p = 0.04}$
Food neophobia (8–40)	21.7 ± 6.2 [a]	21.7 ± 5.1 [a]	22.1 ± 6.3 [a]	19.5 ± 6.4 [a]	F = 1.2, $p = 0.27$ gender $\boldsymbol{p = 0.01}$

Different letters in rows indicate significant differences ($p < 0.05$) from Tukey's HSD test. Values in bold show a significant difference at $p < 0.05$.

The segments did not differ in terms of food familiarity. However, the familiarity score was different across gender ($p = 0.04$), as girls had a slightly higher familiarity score compared to boys for seven of the items (milk chocolate, pineapple, grape, kiwi, green beans, fruit yogurt, and strawberry sorbet). The familiarity of the different food items was also shown to be significantly different ($p < 0.001$) with milk chocolate (4.3 ± 0.6) and apple (4.3 ± 0.7) having the highest familiarity score, while rucola (2.2 ± 1.2) and green beans (2.4 ± 0.9) were the least familiar. There was a significant positive correlation (r= 0.50, $p < 0.001$) between children's stated liking and food familiarity.

The computed Cronbach's alpha on the food neophobia measure was 0.80 showing good internal consistency of the questionnaire. Our data did not show a significant difference in food neophobia across segments ($p = 0.27$), indicating no systematic relationship between taste responsiveness scores and food neophobia. However, there was a gender effect ($p = 0.01$) indicating that boys were more neophobic compared to girls.

4. Discussion

4.1. Children's Responsiveness to the Basic Tastes

The use of model food samples with varied concentrations of tastant (sucrose and sodium chloride) was shown to be effective in inducing different intensities of target taste sensations (sweetness and saltiness, respectively). Sucrose has been reported as a strong suppressor for bitter and sour taste [54]. The mean intensity perception of sweetness in GF gradually increased with sucrose concentration and at the same time both sourness and bitterness gradually decreased. Salty and umami tastes could enhance each other since these tastes work synergically [71,72]. However, umami intensity was not affected by the different concentrations of sodium chloride in VB samples in this study. This could be due to confusion of umami taste with saltiness or bitterness [73], since umami has been reported as the least familiar taste compared to other basic taste modalities in children aged 7–11 years [74].

Our subjects showed quite distinct differences in taste responsiveness for sweetness, sourness, bitterness, and saltiness (but not in umami) measured in the model food samples varying in sucrose (GF) or sodium chloride (VB) concentrations. It was thus possible to characterize the children into four segments with distinctive taste responsiveness profiles: high responsive to bitter and sour (S1), low responsive to sweet (S2), generally low responsive to all basic tastes with the lowest responsiveness to bitterness and sourness (S3), and generally high responsiveness to all basic tastes with the highest responsiveness to sweetness, saltiness, and umami (S4).

There were no significant differences for basic taste responsiveness across genders. This confirms previous work where no differences were found between boys and girls of a similar age group for their basic taste responsiveness measured in water solutions [11]. Moreover, PROP intensity was in accordance with the segments' configuration, as the children who showed to be highly responsive to bitter and sour tastes (S1) and the children who were generally responsive to all basic tastes (S4) rated PROP intensity higher than the other two segments. These results further corroborate previous findings, as PROP intensity has previously been reported to be positively associated with the perceived intensity of basic tastes in children [8,11,75].

The suppression effect of sweetness (from sucrose) on bitterness and sourness intensity perception in GF was significantly related to the different taste responsiveness profiles of the four segments. In fact, sucrose addition in GF samples significantly suppressed sourness and bitterness intensity perception only in subjects with high responsiveness to sweetness (S4) and low responsiveness to sourness and bitterness (S3). On the other hand, a low responsiveness to sweetness (S2) or a high responsiveness to sourness and bitterness (S1) strongly lowered the sucrose suppression to bitterness and sourness intensity. Taste responsiveness also affected the discrimination ability of subjects among samples with increasing sucrose concentration in GF. S4 showed a sharp increase in perceived sweetness intensity at the highest sucrose concentrations (GF40-GF160, Figure 3a), this segment also significantly perceived decreased sourness and bitterness across GF samples in parallel with the increase of sucrose. This indicates that high-responsive children are more sensitive towards variations in tastant concentration [46,76]. Highly responsive subjects are able to perceive smaller variations of different tastant concentrations compared to less responsive subjects [46]. However, this phenomenon was not observed in VB samples for salty and umami tastes, as S4, which was the most responsive segment to these tastes, did not discriminate the different intensity levels among the samples. This indicates that different tastants and concentrations have different suppression and enhancement effects, and may influence taste intensity perception differently [72]. Another possibility could be that children may have already perceived a strong saltiness sensation in VB0 because the broth itself already contain salt (10 g/L), therefore further addition of salt in VB did not significantly increase saltiness perception. Moreover, children might also confuse the tastes of umami and salty [74] which may also influence the result in this study. In addition, the model food matrix of VB as "drink" samples and the fact that it was evaluated at room temperature may influence the intensity perception of children, as it is very uncommon to drink cold broth.

4.2. Relationships between Taste Responsiveness Segments and Liking of the Model Foods: Supression of Warning Sensation

Liking for GF samples was significantly different across segments but was not affected by sucrose concentration except for S3. Children in S1 and S2 were demonstrated to have a lower liking score for GF samples compared to the other segments. Sweetness suppression to warning sensations (bitterness and sourness) was probably not very effective due to high responsiveness to bitter and sour tastes in S1, and due to low responsiveness to sweet taste in S2. In addition, S2 was also moderately responsive to bitterness. In both segments (S1 and S2), the increase of sucrose concentration had no or very slight impact on sweetness intensity, and this was combined with a constant sourness intensity and only a slight decline in bitterness intensity. These results might explain the overall lower liking for GF observed in S1 and S2. Children in S4 were very responsive to sweetness, and this sensation was perceived as strong even at 0 g/L of sucrose addition (GF0) and increasingly high along with the increase of sucrose concentration. This possibly explains the same high liking score for GF samples regardless of the sucrose concentration in S4. In S3, sucrose addition significantly increased the intensity of sweetness and decreased bitterness intensity, thus explaining the significant increase of liking in GF across sucrose concentrations observed in this group. Subjects in S3 also had the lowest responsiveness for sour and bitter tastes. For these subjects, an effective suppression of the warning sensations of sourness and bitterness occurred by addition of sucrose.

S4 consisted of subjects with high taste responsiveness, and it is possible for these subjects to enjoy their foods at lower concentration of tastants and be satisfied at this level; their expectations may be met at lower levels of tastants compared to less sensitive subjects [77]. In contrast, subjects with low taste sensitivity will seek a higher degree of tastant concentration to meet their hedonic expectation [77,78]. This could be the reason why subjects in S3 liked the sweetest sample the most and kept increasing their liking with the increase of sucrose concentration. Indeed, S3 showed a generally low responsiveness to all basic tastes. In line with the previous literatures, our results further proved the strong association of sweetness with acceptance [18,79]. Furthermore, a previous study indicated that higher bitter sensitivity could hinder preferences toward bitter-sour drinks such as grapefruit juices in 9–11-year-old children [28]. This is in line with our results, since S1 and S2, both associated with highly responsive and moderately responsive subjects to bitter taste, respectively showed a lower overall liking score in GF.

4.3. Relationships between Taste Responsiveness Segments and Liking of the Model Foods: Role of Target-Taste Levels and Product Choice

Previous studies [80–82] classified three different groups of subjects according to their hedonic response to sweetness. The sweet likers group represented subjects who increase their liking as sweetness intensity increased (positive correlation). The inverted U-shape group is characterized by subjects who have a maximum liking for a certain sweetness intensity, whereas after this point their liking will decrease. The sweet dislikers group is characterized by subjects who decrease their liking when sweetness intensity is increased (negative correlation). According to our results, children in S3 (less responsive) could be categorized as sweet likers since their hedonic response increased significantly in parallel with the increase of sucrose concentration across the GF samples.

There were no significant effects of the taste responsiveness segments on the liking of VB samples. We assumed this was due to the strong saltiness intensity because the vegetable broth powder itself already contains sodium chloride as one of the ingredients at around 10 g/L. Moreover, in contrast to grapefruit juice, broth is not normally consumed by itself in a real-life situation. It is unusual to serve vegetable broth as a sample drink solely, therefore this may have led to unreliable hedonic responses despite clear differences in taste responsiveness. In association with the GF results, the VB results show that the relationship between taste responsiveness and liking is product and basic taste-dependent in addition to being subject-dependent.

4.4. Relationships between Taste Responsiveness Segments, Stated Liking and Familiarity

There was no significant pattern between the children's segments on taste responsiveness and their stated liking of the selected food items. Children's food liking is not solely affected by taste responsiveness; other extrinsic factors such as food exposure [83], parental modelling and feeding practices at home [84], and socio-demographic condition [85] were reported to be strongly associated with children's food acceptance. Our results did not show any significant relationship between taste responsiveness and familiarity; this corroborates a previous study [58] that reports no association between bitter responsiveness of PROP and familiarity of vegetables differing in bitterness and astringency levels in an adult population. Furthermore, our data demonstrated a positive correlation between food familiarity and stated liking, indicating that the more often children are exposed to certain foods, the more they will become familiar with the foods, which could increase their acceptance [83,86–88].

4.5. Relationships between Taste Responsiveness Segments, Food Choice, and Food Neophobia

There were no significant differences in taste responsiveness segments in terms of food choice. However, there was a trend whereby the children who were responsive to bitterness and sourness (S1) and children who were less responsive to sweetness in addition to being moderately responsive to bitterness (S2) had a lower choice score for bitter/sour food option compared to the other segments. This indicates that these segments tended to not prefer bitter and/or sour food options. This result is in line with previous research which reported that adult subjects with high responsiveness to bitterness and sourness preferred foods that were less bitter and/or sour [89]. Moreover, bitter taste is strongly associated with food aversion [18] and children in S1 and S2 have higher responsiveness to bitter taste which makes them may avoid intense bitter foods. However, we have to consider that the selection of food items for the fruits, juices and desserts categories was based on sensory characterization reported by adult trained panelists [56] and not by preadolescent children. This could lead to a bias as children have a different taste intensity perception from adults [16,79,90,91]. In addition, the CATA-based sensory characterization of vegetables that was used for the selection of vegetable items was evaluated by Italian preadolescents, while the present study was conducted with Norwegian preadolescents. Cultural differences in sensory perception might occur [92] and influence the results in choice score preference since taste sensitivity in children aged 6–9 years has been reported to be significantly different across different countries [13].

The high internal consistency in the Norwegian version of the ICFNS (Cronbach's alpha 0.8) was in line with previous validations of the scale in other languages [65]. Corroborating previous literature, we observed a tendency for boys to be more neophobic than girls [93,94]. However, it should be noted that no such gender effect was reported in a larger cross-cultural study also using the ICFNS [65]. Further, no systematic relationship between taste responsiveness scores and food neophobia occurred, indicating that a neophobic character trait poorly relates to taste perception ability. Similarly, Mameli et al. [95] reported that despite clear differences in taste recognition ability, fungiform papillae density, and responsiveness to PROP, no significant differences emerged in food neophobia scores between a group of Type 1 diabetics and a control group in children aged 6–15 years. Lafraire et al. [96] have highlighted the important role of cognitive, social, and environmental factors in food neophobia and picky/fussy eating behaviour.

4.6. Remote Sensory Testing

An original aspect of our study is that, due to the Covid-19 regulations, the sensory testing was conducted in schools with a teacher physically present in the classroom, while the experimenters interacted remotely via video conference call with the children. Some technical challenges need to be considered when running sensory testing remotely, such as the availability of devices (laptop or tablet) for each child, a large screen, camera, and speaker equipment in the classrooms to allow interaction with the experimenters, and a stable internet connection. In our case, the remote testing was technically easy to set up as each child was already equipped with a tablet or laptop provided by their schools. Moreover, many Norwegian preadolescents use their school tablet or laptop as their learning device at school as well as for homework on a daily basis, making them fully autonomous for the online set up and testing. In addition, the class setting was also equipped with a smartboard or smart screen, speaker, and school Wi-Fi which made the remote test possible.

After over a year of the Covid-19 pandemic, more preadolescents in Europe are expected to have received equipment and increased their digital literacy skills to adapt to online learning. This creates a new potential for application of remote sensory testing with preadolescents. Moreover, this method also allows recruitment of participants from other regions than where the experimenters' working place is located, as long as the test samples can be delivered. Finally, remote testing is less invasive into the children's comfort space; while physical testing in schools involves strangers (experimenters) invading the classroom, which may be stressful for timid children and exciting for extrovert children [97], remote testing keeps the experimenters on screen. Physical interactions only occur with familiar, safe adults from the school personnel. This may potentially reduce both stress and excitement among children, favoring a better focus on the task. Further studies are recommended to validate remote testing as an approach of data collection for this age group.

4.7. Implications for Strategy Development in Children's Food Acceptance

Results of the present study indicate a prominent role of taste responsiveness on preadolescents' acceptance of food characterized by warning sensations. Individual variations in responsiveness to both liked and disliked sensations not only modulates the perceived intensity but shapes taste interactions and hedonic responses. Our results indicate that strategies aimed at improving acceptance through the use of suppressors of generally disliked sensations can be more or less effective in subject groups varying in responsiveness to basic tastes and suggest the need for taking into account individual differences. For example, the food formulation strategies using cross-modal interactions (i.e., taste/texture/odor) could help to optimize food formulation [98] in order to overcome the low acceptance due to differences in taste responsiveness. Moreover, individual differences in taste responsiveness could modulate the effectiveness of masking strategies for tastes that generally have a low acceptance such as bitter taste. For example, masking bitterness with sugar (sweet) may be less effective to increase the acceptance of bitter vegetables in children characterized by high responsiveness to bitter taste, and thus other strategies such as repeated exposure may be suggested [86,88].

Increased awareness of the importance of individual perceptual differences in driving food preference and choice has been reported previously [47]. This calls for sensory-driven solutions in personalized nutrition recommendations to help vulnerable groups (i.e., obese children) to adopt a long-term healthy eating habit. Moreover, food preference is not shaped by taste sensitivity solely, but other extrinsic factors may strongly influence children's food preferences [13,85]. This requires further research to explore a wider perspective on how taste responsiveness impacts both food preference and response to interventions, as well as investigating extrinsic factors related to food preferences in children. The implementation for "real-life" intervention cannot rely on sensory aspect only; however, a deeper understanding in sensory perceptions and hedonic responses to food might help to interpret food related behaviour and could effectively complement other actions aimed to improve healthy eating behaviour in children. Communicating these knowledges to professional and public bodies would allow the establishment of more effective healthy eating interventions which take into account the diversity of shaping food habits including individual differences in sensory perceptions.

4.8. Study Limitations

There were some limitations in conducting this study. First, we could not fully avoid interactions between children, as some of the classrooms were not large enough to arrange a satisfactory distance between peers. However, instructions on working individually during the test as well as supervision by the teacher and through video call ensured that interactions were kept to a minimum. Second, the food items selection for stated liking, familiarity, and food choice focused on different intensity levels for sweet, sour, and bitter but did not involve salty and umami foods. We suggest considering foods representing all basic tastes for further investigation. Third, model foods that are not normally consumed in ecological settings (such as room-temperate vegetable broth) do not seem to be appropriate test samples. Alternative food matrices should be identified for future studies on saltiness and umami. Lastly, the segments formed consisted of a low number of subjects; repeated studies and/or larger numbers of participants are suggested in future research to confirm the results obtained from this relatively small number of subjects.

5. Conclusions

This study aimed to investigate the relationships between taste responsiveness and liking in preadolescent children. Model food samples of grapefruit juice and vegetable broth with different concentrations of sucrose and sodium chloride, respectively, were employed to measure children's perceived taste intensity and their liking. Four segments were formed according to children's individual differences in taste responsiveness. The results showed that taste responsiveness significantly influenced the liking of grapefruit juice samples. However, children expressed little hedonic variations for the broth, despite clear significant variations in taste responsiveness for the same samples, indicating that the relationship between taste responsiveness and liking is product and target-taste dependent in addition to being subject-dependent.

This study also demonstrates that the suppression effect of sweetness on warning sensations of bitterness and sourness is associated with taste responsiveness in preadolescent children. Children who were highly responsive to bitterness and sourness and less responsive to sweetness did not experience a suppression effect of warning sensations by sweetness and this hindered the liking of model food sample of grapefruit juices. On the contrary, children who were least responsive to bitter and sour tastes showed increased liking as sucrose concentrations increased. This result calls for the development of different strategies specific to children's taste responsiveness profiles, to increase their acceptance for foods dominated by warning sensations of sourness and bitterness such as fruits and vegetables. This study also confirmed a positive association between food familiarity and stated liking. A gender effect was observed for familiarity and neophobia, where boys were more neophobic and had lower familiarity scores compared to girls.

To our knowledge, this is the first study that employs a remote sensory evaluation method with preadolescent children to investigate their basic taste responsiveness and liking in model food samples. The usage of remote sensory testing as an alternative approach for sensory data collection in preadolescents is suggested for further study. Further research may investigate if the associations between taste responsiveness and liking are stable across different model food samples, basic tastes, and cultures.

Supplementary Materials: The following are available online at https://www.mdpi.com/article/10.3390/nu13082721/s1, Table S1: Selected food items for familiarity and stated liking, Table S2: Selected food items for food choice preference, Table S3: Statistical results (Cochran's Q test) from a sensory characterization of vegetables with Check-All-That-Apply (CATA) in Italian preadolescent children (*n* = 121), Table S4: Norwegian version of the Italian Child Food Neophobia Scale (ICFNS).

Author Contributions: Conceptualization, E.E.; V.L.A.; C.D.; S.S.; I.B. and J.S.; methodology, E.E.; C.D.; V.L.A.; S.S. and J.S.; validation, E.E.; V.L.A.; C.D.; S.S. and J.S.; investigation E.E.; J.S.; V.L.A.; resources, E.E.; J.S. and V.L.A.; data curation. E.E.; I.B. and C.D.; formal analysis, E.E. and I.B.; writing—original draft preparation, E.E.; writing—review and editing, E.E.; C.D.; V.L.A.; I.B.; S.S. and J.S.; Visualization, E.E.; Supervision, C.D.; V.L.A. and I.B. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement: The study was conducted according to the guidelines of the Declaration of Helsinki, and the ethical approval has been granted by The Norwegian Center for Research Data (NSD) No. 715734 and refers to the General Data Protection Regulation (GDPR) for the use of personal data.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data presented in this study are available at doi:10.5281/zenodo.5167132.

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