Taste dysfunction in children – a clinical perspective and review of assessment methods

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Abstract
Taste dysfunction has been associated with aging and is therefore thought to be less common in children. However, children can face medical conditions influencing their taste function. Measuring and understanding taste dysfunction in children may foster the development of treatments/interventions mitigating the detrimental effects of taste dysfunction on children’s appetite and quality of life. But measuring loss of taste function requires adequate tools. This review was conducted to (1) provide an overview of etiologies (i.e., disease and iatrogenic) associated with taste dysfunction in a pediatric population; (2) to investigate which tools (psychophysical tests and questionnaires) are available to assess taste function in children; and (3) to identify what tools can be and are actually used in clinical practice. It is concluded that only a minority of available tools to assess taste function in children are readily suitable for a pediatric clinical setting. Considering the profound impact of taste dysfunction in the pediatric setting, developing and implementing a standard taste test that is sensitive, simple, and practical to use with children is pertinent.

Keywords: taste, taste dysfunction, children, psychophysical test, self-report
Introduction

The chemical senses – smell and taste – are important regarding food intake, safety, and quality of life (Santos et al. 2004; Croy et al. 2014). That is as true for children as it is for adults. However, most individuals do not acknowledge the importance of their chemical senses until they lose it. It should be noted that individuals complaining of taste problems often suffer from smell loss in the absence of any true taste dysfunction, as differentiating taste problems from smell loss is difficult (Deems et al. 1991). In general, taste disorders are rare and have been reported in only 5% of the population (Welge-Lussen et al. 2011). Little is known about taste dysfunction in children. In general, it is thought to be very rare as taste disturbances are associated with aging and other factors such as (chronic) medication use or exposure to toxic substances (Hummel et al. 2011).

Taste dysfunction is uncommon in the general population, but (temporary) loss of taste function is quite prevalent in the clinical setting as it can arise from a wide variety of diseases and/or treatments. Previous work in adults has shown that taste dysfunction is most often the result of disorders of the oral cavity, middle ear infections or surgery, trauma, Bell’s palsy, systemic disturbances of metabolism such as diabetes mellitus, or cancer and its treatment (Bromley and Doty 2015). More recently, taste loss has become an important symptom of the coronavirus disease 2019 (COVID-19) infection (Sanasiaya et al. 2020). Further, several medications used alone or in combination have been reported to potentially change taste function or induce an unusual taste sensation. These include very different but commonly prescribed drugs like aspirin (an analgesic), simvastatin (an antilipidemic), and amoxycillin (an antibiotic) (Schiffman 2018).

Like adult patients, children can suffer from a medical condition that will cause taste dysfunction, consequently affecting food intake and quality of life (Laing et al. 2011).
Presumably, the detrimental impact of such dysfunction might be larger in children, as their eating behavior and food preferences are still developing and are strongly influenced by input from the chemical senses. Therefore, the assessment of taste function in childhood is important, as diagnosis and characterization of taste loss may foster the development of more appropriate supportive strategies such as medication or dietary advice (Kershaw and Mattes 2018). Note that a comprehensive assessment of taste function should also include measuring smell function as well (for reviews about measuring olfaction in children, see Calvo-Henriquez et al. 2020; Gellrich et al. 2021).

Over the past decades, several assessment methods have become available to assess taste function in adults. “Taste Strips” or taste solution drop tests are frequently used in a clinical setting to evaluate sensitivity to sweet, sour, salty, and bitter taste (Mueller et al. 2003; Gudziol and Hummel 2007; Landis et al. 2009; Pingel et al. 2010). It should be noted that only Pingel and colleagues included a sample of children (age 5 – 15 years) with the development of their solution-based taste test and provided normative values for this age category.

Next to taste solutions tests, electrogustometry (EGM) is used to assess detection thresholds. With EGM, a probe is touched to the tongue through which a small electric current is applied that can evoke a sour/metallic taste sensation. EGM then does not depend on identifying taste qualities, but does allow for determining threshold measures (Tomita and Ikeda 2002). In addition, questionnaires including patient-reported experiences can be useful for recognition of taste loss or further characterization of a taste disorder.

In sum, little is known about taste dysfunction in childhood. Some etiologies of taste dysfunction in adults may also apply to children, while others don’t. In addition, there seems to be a variety of taste function assessment tools available, at least for adults. However, the question remains what tools can be readily applied in a clinical setting where it is important to be able to
diagnose potential taste dysfunction and to gain insight in the severity of any taste dysfunction. In other words, it is still unclear how taste function – or dysfunction – can be adequately assessed in a pediatric clinical setting. Therefore, this review was conducted to (1) provide an overview of etiologies associated with taste dysfunction in a pediatric population; (2) to investigate which tools (psychophysical taste tests measuring thresholds or identification scores and questionnaires) are available to quantify taste (dys)function in children; and (3) to identify what tools can be and are actually used in clinical practice. Taste tests including hedonic evaluation or taste intensity ratings are not discussed in this review as they are less frequently used for assessing taste function (or taste loss) in a clinical setting.

**Taste dysfunction in childhood**

_as displayed in Table 1, taste dysfunction is associated with several clinical disorders in children. Studies examining medical conditions that might influence taste function in children can be grouped into the following categories: otolaryngology, oncology, obesity, systemic diseases (excluding oncology and obesity), and other conditions. Some studies do show an association between a specific medical disorder (and/or its treatment) and taste function in children. However, results are not always clear-cut and occasionally no apparent association between disorder and taste function is found._

Regarding otolaryngology, taste loss is a potential risk as infections or surgical interventions may affect the gustatory nerves. However, children with recurrent tonsillitis showed no impaired taste function compared to controls (Hill et al. 2017). This was an unexpected
finding as repeated tonsillar infections might affect the glossopharyngeal nerve. Another study
did show reduced taste ability in children with chronic otitis media as compared to controls.
Chronic otitis media refers to inflammation of the middle ear cavity that injures the chorda
tympanic nerve (Shin et al. 2011). In addition, Leung and colleagues found a wide range of taste
dysfunction (5 – 50%) among children who underwent otologic surgery, depending on the
 technique used, compared to taste dysfunction in the general pediatric population (Leung et al.
2009).

Childhood cancer and its treatment seems to change taste function in children with cancer. However, results are equivocal and hard to compare, as studies differ in assessment methods,
timing of the measurements, and types of cancer. Four studies were performed in pediatric
oncology patients, investigating the influence of chemotherapy or blood and marrow
transplantation on taste function. A higher threshold for bitter taste, and more taste recognition
errors, has been found among children receiving chemotherapy compared to controls (Skolin et
al. 2006). In contrast, we found that children with a wide number of cancer diagnoses receiving
chemotherapy are better at identifying sour taste than healthy controls. In addition, we found
indications that bitter and sweet taste sensitivity increases in children from before to after a cycle
of chemotherapy (van den Brink et al. 2020). Regarding blood and marrow transplantation, a
decreased taste function has been found in children with cancer shortly after blood and marrow
transplantation, but this impaired sense of taste resolved within two and six months, respectively,
after transplantation (Cohen et al. 2012; Majorana et al. 2015).

Taste function of children with obesity also seems to be different from healthy controls,
but again, results are inconsistent and differ regarding taste qualities. Seven studies assessed the
relation between obesity and taste function in children. In five studies, taste function of children
with obesity was compared to healthy controls. Although results seem to differ regarding
individual taste qualities, overall taste function of children with obesity is reported to be lower compared to controls in three studies (Overberg et al. 2012; Sauer et al. 2017; Mameli et al. 2019). In addition, 47% to 77% of the children with obesity showed taste detection thresholds below the normal range values as measured with electrogustometry (Obrebowski et al. 2000). More recently, Herz and colleagues failed to find differences in taste sensitivity between children who are overweight/obese and controls (Herz et al. 2020). Moreover, in one study a higher sensitivity to sweet and salty taste among children with obesity was found (Pasquet et al. 2007). The influence of a lifestyle weight management intervention on taste function in children with obesity has also been studied. Improved bitter sensitivity, umami sensitivity, and overall taste function was reported (Kalveram et al. 2021), whereas improvements in sour taste detection and deterioration in sweet taste detection have been reported after a lifestyle weight management intervention as well (Sauer et al. 2017).

Systemic diseases in childhood (excluding oncology and obesity) that might influence taste function, and probably food preferences and dietary intake as well, include cystic fibrosis, diabetes mellitus type 1, and kidney disease. Taste identification of children with cystic fibrosis was similar to healthy children (Laing et al. 2010). Children with type 1 diabetes, however, showed a lower ability to correctly identify taste qualities compared to controls, especially for bitter and sour taste (Mameli et al. 2019). Children with chronic kidney disease (CKD) exhibited a lower taste identification ability than clinical controls (Correa et al. 2015). Another study found that taste function diminishes especially the ability to taste sweet and bitter, in children with CKD when their estimated glomerular filtration rate (eGFR) decreases (Armstrong et al. 2010).

Other conditions in which taste function might be impacted are summarized in this section. Detection thresholds of children with asthma were different from healthy children, requiring higher concentrations of sucrose and urea to perceive the taste for children with asthma
(Arias-Guillen et al. 2020). Moreover, children with autism spectrum disorder can display extreme food selectivity (Schreck and Williams 2006), which perhaps is partly the result of abnormal taste function. But in children with autism, no differences in detection thresholds were found relative to controls, although they were less able to correctly identify sour taste (Bennetto et al. 2007). BMG, an inflammatory disorder, affects the tongue. However, taste function of children with BMG was not impaired (Vieira et al. 2011). Lastly, taste function after surgical tongue reduction was evaluated in children with an overgrowth disorder (Beckwith-Wiedemann syndrome) that causes macroglossia (Maas et al. 2016). No long-term consequences regarding taste function were found in this group of patients either.

In sum, there is clear evidence that certain childhood diseases, conditions or medical treatments affect children’s taste function. However, it is not always clear what that altered taste function comprises.

Taste assessment in childhood

General aspects. Taste cells begin to form at 7 or 8 weeks of gestation (Witt and Reutter 1997). The sense of taste is anatomically well-developed at birth, however, it still develops over the lifespan. For example, neonates are already able to react to pleasurable (sweet) and aversive (bitter, sour) taste stimuli, but they react neutrally to salty taste. Liking for salt emerges a few months later (Beauchamp et al. 1986; Steiner et al. 2001).

It remains unclear whether children have similar abilities as adults to detect various taste qualities. Some scholars found that children have similar taste thresholds as adults, whereas others report that children have a lower taste sensitivity than adults (Anliker et al. 1991; James et al. 1997; De Graaf and Zandstra 1999). In addition, there is some evidence that gustation matures a bit faster in girls (James et al. 1997).
Table 2 provides an overview of psychophysical taste tests that have been developed or adapted for children by using detection thresholds (the lowest concentration of a solution consistently detected as being different from a control, usually water), recognition thresholds (the lowest concentration of a solution consistently recognized as the tastant) or taste identification. In general, these taste tests can be used in both clinical or research settings, although some differences between applications should be noted.

In a clinical routine, it is of great important that a taste test can be easily administered, renders individual scores that can be compared to normative data, has both high sensitivity and high specificity, and is relatively brief. In this setting, taste assessment largely focuses on the evaluation of the four taste qualities (i.e., sweet, sour, salty, and bitter) to screen or diagnose for taste dysfunction. Within the context of research, however, any patient taste test scores are often compared with scores from a matched, healthy comparison/control group. The goal in such research is not to diagnose taste dysfunction, but to qualify and quantify loss of taste function within a specific patient population versus healthy controls. In addition, the effects of genetics, age, or food habits on children’s taste sensitivity are often studied for research purposes. Taste tests within such a research setting frequently focus on a specific taste quality (e.g., sweet taste). Nonetheless, these laboratory validated methods used to assess children’s taste sensitivity might still have clinical utility and are discussed below alongside clinical tests.

Clinical assessment tools. We found four taste tests and one questionnaire that are available for investigating children’s taste function in a clinical setting. Majorana and colleagues aimed to
develop a standardized clinical evaluation of children’s taste sensitivity (5 – 12 years) (Majorana et al. 2012). Two concentrations (high and low) of each taste quality are provided serially with pipettes and the child has to identify each tastant (sweet, salty, sour, bitter, or water). The lowest concentration of each taste quality that is correctly identified and distinguished from water is considered a child’s taste threshold. Although this test seems reliable (test-retest reliability; \( r = 0.74 \)), the low number of variations in taste concentrations makes it questionable whether this test can truly detect any taste dysfunction. Furthermore, data was obtained from a relatively small sample (n = 40) of healthy children and normative data are lacking.

Another simple taste test was developed for children with macroglossia, which is caused by an overgrowth disorder (van der Horst et al. 2010). These children need to undergo a partial tongue reduction in early life, which might influence taste function. This test, which consists of two parts, can still evaluate taste function after surgery. The first part determines at what part of the tongue taste perception is optimal, by applying a concentrated solution of sucrose, sodium chloride, citric acid, and quinine hydrochloride on each of eight different regions. The second part determines correct identification of sweet, sour, salty, and bitter by using three solutions for each taste quality. Again, all eight regions of the tongue are touched with a saturated cotton swab and the child is asked what taste is perceived.

A clinical gustatory screening test for school-age children, including a whole-mouth and regional task, was developed by Laing and colleagues (Laing et al. 2008). During both tasks, a single suprathreshold taste solution is used for each taste quality which has to be identified by the child from a set of three photographs (one photo represents water in a glass, two represent tastants). During the whole mouth test, the child has to sip and identify the five samples (sucrose, sodium chloride, citric acid, quinine hydrochloride, and purified water). During the regional test, the four tastants and a water sample are presented to each of four regions on the dorsal surface of
the tongue, resulting in a total of 20 presentations. This simple screening test includes normative data from a large sample (n = 232) and can be used to diagnose taste dysfunction in children.

Leung et al. assessed the reliability of electrogustometry in children, in order to investigate whether this tool is applicable in a pediatric otolaryngology setting (Leung et al. 2009). Electrogustometry was found to be reliable (Cronbach alpha = 0.82) in children and, with exception of those under the age of six years, most children were able to understand instructions and complete the test.

Lastly, one questionnaire regarding taste function in children with cancer receiving chemotherapy is available: The Taste Alteration Scale for Children with Cancer Receiving Chemotherapy (TAS-CrC). This questionnaire aims to evaluate self-reported taste perception and taste alterations regarding sweet, sour, salty, and bitter among children with cancer aged 8 – 18 years (Bilsin and Bal Yılmaz 2018). This scale includes nine items rated on a 5-point Likert scale of which seven items address taste dysfunction and two address smell dysfunction. Items regarding taste alteration were obtained from a literature review and gathered into an item-pool, which was evaluated by experts. Moreover, a validity study (including content and construct validity) was performed among experts and a reliability study was performed to assess internal consistency of the scale. Both Cronbach’s alpha reliability coefficient (alpha = 0.88) and test-retest reliability ($r = 0.97, p < 0.01$) were high. The TAS-CrC can thus be considered valid and reliable.

Other tools. Six other taste assessment methods are listed in Table 2, which can be used in children. Recently, an extensive protocol – the Taste Detection Threshold (TDT) test – for preparing and determining detection thresholds for sucrose, sodium chloride, and monosodium glutamate (MSG) was published and this protocol can be used in children as young as six years.
(Joseph et al. 2021). The TDT test uses a two-alternative forced-choice (2AFC) staircase procedure, which has already been employed in children in previous studies (Bobowski and Mennella 2015; Joseph et al. 2016; Petty et al. 2020). On average, it takes 15 minutes per tastant before a detection threshold is reached.

Another taste sensitivity test, focusing on very young children (3 – 6 years), has been developed in order to measure detection thresholds for sucrose and urea, also using a 2AFC staircase procedure (Visser et al. 2000). Especially in young children, a forced-choice paradigm produces more valid results compared to a non-forced procedure. Although a fairy tale was used to enhance motivation and engagement during the test, a loss of interest over time was noticed by the authors in the participating children.

Engaging children (especially young children) in a taste test is not easy, but some researchers have developed interesting tests that attempt to involve the young child in a playful manner. Knof and colleagues (Knof et al. 2011), for example, developed a taste detection threshold test in which a board game is used and children are addressed as ‘taste detectives’. For each tastant (sucrose, sodium chloride, caffeine, and monosodium glutamate), five concentration steps are investigated. Another taste test focuses on pre-schoolers (3 – 4 years) and uses a fairy tale to introduce five magic characters (tastants) who all drank magic water that differed in taste (Vennerød et al. 2017). Although both these tests focus on taste sensitivity in healthy children, rather than identifying taste loss, these are attractive methods showing good test-retest reliability.

Lastly, two older methods are still frequently used or referred to when measuring taste function in children. Firstly, the threshold procedure from Anliker and colleagues focuses on the assessment of detection thresholds for the bitter compound 6-n-propylthiouracil (PROP) using 14 dilution steps by a 2AFC staircase procedure, but also includes a suprathreshold intensity rating test for PROP and sodium chloride (Anliker et al. 1991). Concentrations used in this test
procedure are frequently chosen or adapted in later studies (Mennella et al. 2005). Secondly, Nilsson and Holm aimed to develop a quick and simple test method for investigating taste recognition thresholds, as they considered previous methods as too time-consuming and therefore not suitable for teenagers (Nilsson and Holm 1983). Their whole-mouth test determines recognition thresholds for sweet, salty, sour, and bitter solutions by presenting 10 solutions of each tastant in increasing concentrations.

**Tests used in clinical practice**

The question arises whether taste tests developed for children, as described in Table 2, are actually used – or could be used – in clinical practice. From a clinical perspective, a test is preferably brief, easy to prepare and administer, and includes normative data to be able to diagnose potential dysfunction.

Regarding clinical assessment tools, taste loss in children can be reliably diagnosed by electrogustometry (Leung et al. 2009). Further, normative data are available for the clinical gustatory screening test for children aged 5 – 7 years (Laing et al. 2008). For this screening test, children aged 5 years should be able to identify at least three of the five taste substances, whereas 6- and 7-year-olds are expected to identify four substances. However, the screening test itself has not been used in later studies. Instead, an extended identification task including five different concentrations of each taste stimulus has been applied (Armstrong et al. 2010; Laing et al. 2010; Cohen et al. 2012; Correa et al. 2015). Similar to the original screening test, children aged 5 years should be able to identify at least three concentrations of each tastant, and older children at least four concentrations of each tastant to be considered normogeusic. Unfortunately, an extensive description of this latter procedure is lacking, and its test-retest reliability does not appear to be very high \(r = 0.52\) (Armstrong et al. 2010; Laing et al. 2010).
The other taste tests (van der Horst et al. 2010; Majorana et al. 2012) and validated questionnaire (Bilsin and Bal Yılmaz 2018) described above lack normative data and thus seem to be rarely used in clinical practice. This might be due to the fact that those tools are restricted to specific patient groups (as is the case with the taste alteration scale for children with cancer) or are time-consuming to prepare (as is the case with various taste solution tests).

Another time-consuming approach is the Taste Detection Threshold test (Joseph et al. 2021). This test does include an extensive manual for preparing taste solutions. However, preparation requires laboratory skills and facilities which makes this test procedure not particularly convenient for the pediatric clinician (and patient) who would likely prefer to use a point-of-care (or bedside) test. Moreover, although detection thresholds do rely less on the verbal/cognitive skills of the child, staircase procedures can be lengthy (Anliker et al. 1991; Visser et al. 2000; Joseph et al. 2021). Test duration may not be overly problematic when assessing taste sensitivity of healthy children in a laboratory setting and when children can take a break in between sessions. However, in a clinical context where children are ill, the duration of testing should be kept to a minimum.

One convenient taste test that is ready made and does not require a lengthy procedure is the “Taste Strips” test. It is often used to assess taste function or taste loss in children (Vieira et al. 2011; Overberg et al. 2012; Hill et al. 2017; Sauer et al. 2017; Mameli et al. 2019; Mameli et al. 2019; Herz et al. 2020; van den Brink et al. 2020; Kalveram et al. 2021). This test is commercially available, has a long shelf-life, and is easy to use at the bedside. These features explain its appeal. However, this test has not been validated in children and available normative data are restricted to adults.
Discussion and conclusions

Taste function is important for physical and psychological well-being, which is as true for children as it is for adults. The present review shows that several diseases (and treatment) in childhood are associated with taste dysfunction, but only a few standardized taste tests have been developed to assess or diagnose such taste dysfunction in a pediatric clinical setting. Their use is limited as most of these tests are not commercially available and often depend on self-prepared taste solutions. Furthermore, normative data are often lacking. This is not problematic when applying one of these tests in the context of academic research, but it does limit their clinical utility. Especially within a clinical setting, one wants to be able to quickly diagnose potential taste dysfunction if taste is expected to be compromised as a result of disease burden or treatment.

A standardized taste test is still needed that is suitable for children and can be easily applied in clinical practice. The “Taste Strips” test appears a suitable candidate for this purpose, however, normative values of the Taste Strips for children still need to be acquired. In addition, its relatively low test-retest reliability \((r = 0.68, \text{ in adults})\) might hinder an accurate distinction between normogeusia and dysgeusia when tracking taste function over time and is thus of some concern.

Apart from the scarcity of convenient psychophysical taste tests for the pediatric clinical setting, there is also a lack of validated questionnaires concerning taste perception in children. Such a questionnaire only appears to exist for children with cancer (Bilsin and Bal Yılmaz 2018). Similar questionnaires would be very useful in clinical practice for quick screening of taste function and associated problems in children. Further research is needed to develop questionnaires with which the clinician can quickly recognize or monitor taste loss/change in children in general. Self-reported taste dysfunction should always be followed up by a
psychophysical test, given the relatively poor accuracy of self-report measures (Soter et al. 2008), but that does not obviate the utility of such a questionnaire.

To recapitulate, a variety of childhood diseases and disorders are associated with taste changes or even dysfunction. Impaired taste function is aversive and thus negatively impacts quality of life in pediatric patients. Furthermore, as taste dysfunction has important implications for food intake on the short term and for the development of dietary habits and food preferences on the longer term, monitoring taste function in pediatric clinical practice seems pertinent. Such screening, however, requires adequate taste testing instruments. Clearly, there is still a need for the development of a practical, reliable, and child-friendly taste test that accurately measures taste function and that can be used in clinical practice as a point-of-care test.
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| Diagnosis                      | Author                      | Subjects (n)                                                                 | Age (years) | Stimuli (number of solutions)                                                                 | Taste test                             | Outcome                                                                 |
|-------------------------------|-----------------------------|------------------------------------------------------------------------------|-------------|---------------------------------------------------------------------------------------------|----------------------------------------|-------------------------------------------------------------------------|
| Asthma                        | Arias-Guillen et al. 2020   | Patients (n = 46); controls (n = 45)                                         | 6 – 7       | Sucrose (13); quinine hydrochloride (15)                                                     | DT using taste solutions, 2AFC staircase | Children with asthma required higher concentrations to discriminate between the tastant and distilled water. |
| Autism                        | Bennetto et al. 2007        | Autism (n = 21); controls (n = 27)                                           | 10 – 18     | Sucrose (1); sodium chloride (1); citric acid (1); quinine hydrochloride (1)                | DT using EGM, 2AFC staircase; regional ID using taste solutions, 4AFC | Children with autism were less able to identify sour taste compared to controls. Detection thresholds were not different between groups. |
| Benign migratory glossitis    | Vieira et al. 2011          | Patients (n = 20); controls (n = 20)                                         | 8 – 18      | Sucrose (3); sodium chloride (3); citric acid (3); quinine hydrochloride (3)                | ID using Taste Strips, 5AFC           | No differences were found between patients and controls regarding identifying taste stimuli. |
| Cancer Chemotherapy           | Skolin et al. 2006          | Patients (n = 10); controls (n = 10)                                         | 11 – 17     | Sucrose (9); sodium chloride (9); citric acid (9); quinine hydrochloride (9)                | RT using taste solutions, 5AFC staircase | The taste test was performed between two chemotherapy cycles, showing higher thresholds for bitter taste among patients. Also, patients made more taste recognition errors compared to controls. |
| Cancer BMT                    | Cohen et al. 2012           | Patients (n = 10)                                                             | 8 – 15      | Sucrose (5); sodium chloride (5); citric acid (5); quinine hydrochloride (5)                | ID using taste solutions, 3AFC         | Taste tests were performed at baseline and after BMT (1-month, 2-month follow-up). Taste dysfunction was found among one third of the patients one month after BMT, but taste function was normalized two |
| Disease                          | Study Authors                          | Study Subjects                                                                 | Stimuli Duration | Stimuli                                    | Identification Method | Taste Test Details                                                                                                                                                                                                 |
|---------------------------------|----------------------------------------|--------------------------------------------------------------------------------|------------------|--------------------------------------------|----------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Cancer HSCT                     | Majorana et al. 2015                   | Patients (n = 51)                                                                | 3 – 12 months    | Sucrose (4); sodium chloride (4); citric acid (4); quinine hydrochloride (4) | ID using taste solutions, 5AFC | Taste tests were performed before, during, and after HSCT. During HSCT, threshold value means increased for the four stimuli. Six months after HSCT, taste function was normalized. |
| Cancer Chemotherapy             | van den Brink et al. 2020              | Patients (n = 31); controls (n = 24)                                            | 6 – 18 months    | Sucrose (4); sodium chloride (4); citric acid (4); quinine hydrochloride (4) | ID using Taste Strips, 5AFC | Taste tests were performed before and after a cycle chemotherapy, showing higher sweet, bitter, and total taste scores after a cycle of chemotherapy compared to before the start of that cycle. When compared to controls, patients had a higher sour taste score. |
| Cystic fibrosis                 | Laing et al. 2010                      | Patients (n = 42); controls (n = 42)                                            | 5 – 18 months    | Sucrose (5); sodium chloride (5); citric acid (5); quinine hydrochloride (5) | ID using taste solutions, 3AFC | No significant differences in taste function were found between children with cystic fibrosis and controls.                                                                                                           |
| Diabetes mellitus type 1        | Mameli et al. 2019                     | Patients (n = 31); controls (n = 31)                                            | 6 – 15 months    | Sucrose (4); sodium chloride (4); citric acid (4); quinine hydrochloride (4) | ID using Taste Strips, 5AFC | Children with diabetes had lower bitter, sour, and total taste scores compared to controls.                                                                                                                      |
| Kidney disease                  | Armstrong et al. 2010                  | CKD 2 (n = 12); CKD 3 – 5 (n = 20); clinical controls (n =20); healthy controls (n = 20) | 5 – 19 months    | Sucrose (5); sodium chloride (5); citric acid (5); quinine hydrochloride (5) | ID using taste solutions, 3AFC | The ability to identify tastants by children with CKD diminishes as the eGFR decreases. This was observed for sweet and bitter taste and, to a lesser extent, for sour.                                                       |
| Kidney disease                  | Correa et al. 2015                     | CKD 3 – 5 (n = 12); clinical controls (n = 12)                                  | 5 – 18 months    | Sucrose (5); sodium chloride (5); citric acid (5); quinine hydrochloride (5) | ID using taste solutions, 3AFC | Taste loss was more prevalent in children with CKD than in clinical controls.                                                                                                                                          |
| Obesogen                                    | Study (Year)                  | Subjects (n) | Ages (yrs) | Test Solutions | Test Method | Findings                                                                                     |
|--------------------------------------------|-------------------------------|--------------|------------|----------------|-------------|--------------------------------------------------------------------------------------------|
| Macroglossia *Tongue reduction*            | Maas et al. 2016              | Patients (n = 10) | 5 – 18     | Sucrose (4); sodium chloride (4); citric acid (4); quinine hydrochloride (4) | Regional ID using taste solutions, 5AFC | Taste was perceived on the different regions of the tongue, although not always correctly identified. Anterior tongue resection has no long-term consequences for taste function. |
| Obesity                                    | Obrebowksi et al. 2000        | Obese (n = 30) | 10 – 16    | NA             | DT using EGM | 47% – 77% of the children with obesity have detection thresholds below the limit of normal range, depending on the electrode used. |
| Obesity                                    | Pasquet et al. 2007           | Obese (n = 39), controls (n = 48) | 11 – 17    | Sucrose (10); fructose (10); sodium chloride (12), citric acid (7) | RT using taste solutions, 5AFC staircase | Children with obesity had a higher sensitivity (lower RT) to sucrose and sodium chloride than controls. |
| Obesity                                    | Overberg et al. 2012          | Obese (n = 99), controls (n = 94) | 6 – 18     | Sucrose (4); sodium chloride (4); citric acid (4); quinine hydrochloride (4); MSG (4) | ID using Taste Strips, 6AFC | Children with obesity showed a lower ability in correctly identifying salty, umami, and bitter taste, resulting in lower total taste scores compared to controls. |
| Obesity *Lifestyle intervention*           | Sauer et al. 2017             | Obese (n = 60), controls (n = 27) | 9 – 17     | Sucrose (4); sodium chloride (4); citric acid (4); quinine hydrochloride (4) | ID using Taste Strips, 5AFC | Before lifestyle intervention, children with obesity had a lower sour and total taste score compared to controls. After intervention, sour taste scores improved whereas sweet taste scores deteriorated. |
| Obesity                                    | Mameli et al. 2019            | Obese (n = 34), controls (n = 33) | 6 – 14     | Sucrose (4); sodium chloride (4); citric acid (4); quinine hydrochloride (4) | ID using Taste Strips, 5AFC | Children with obesity showed a lower ability in correctly identifying sweet, sour, and bitter taste, resulting in lower total taste scores compared to controls. |
| Obesity                                    | Herz et al. 2020              | High BMI/obese (n = 27); controls (n = 26) | 12 – 16    | Sucrose (4); sodium chloride (4); citric acid (4); quinine | ID using Taste Strips, 5AFC | No significant differences in taste function were found between adolescents with overweight/obesity |
| Disorder                  | Authors (Year)          | Study Group | Age (n) | Taste Stimuli                                                                 | Identification Method | Results                                                                                           |
|--------------------------|-------------------------|-------------|---------|-----------------------------------------------------------------------------|-----------------------|--------------------------------------------------------------------------------------------------|
| Obesity                  | Kalveram et al. 2021    | Obese (n = 102) | 6 – 18 | Sucrose (4); sodium chloride (4); citric acid (4); quinine hydrochloride (4); MSG (4) | ID using Taste Strips, 6AFC | Children with obesity identified sweet taste better compared to other taste stimuli. Total taste score, but also scores for bitter and umami, increased after lifestyle intervention. |
| Otitis media             | Shin et al. 2011        | Patients (n = 42); controls (n = 42) | 3 – 7  | Sucrose (4); sodium chloride (4); citric acid (4); quinine hydrochloride (4) | DT using EGM; ID using taste solutions | Patients showed higher thresholds for sweet and salty, but also higher thresholds on the anterior tongue (EGM), compared to controls. |
| Otology Otologic surgery | Leung et al. 2009       | Patients (n = 99); controls (n = 61) | 4 – 18 | NA                                                                            | DT using EGM          | Taste dysfunction after otologic surgery range between 5 – 50 %, depending on the type of surgery, compared to 9% in controls. |
| Tonsillitis              | Hill et al. 2017        | Patients (n = 64); controls (n = 80) | 6 – 17 | Sucrose (4); sodium chloride (4); citric acid (4); quinine hydrochloride (4) | ID using Taste Strips, 5AFC | Scores for individual taste qualities and total taste were not different between patients and controls. |

Abbreviations: BMI, Body Mass Index; BMT, blood and marrow transplantation; CKD, chronic kidney disease; DT, detection threshold; eGFR, estimated glomerular filtration rate; EGM, electrogustometry; HSCT, hematopoietic stem cell transplantation; ID, taste identification; MSG, monosodium glutamate; NA, not applicable; RT, recognition threshold; 3AFC, three-alternative forced-choice; 4AFC, four-alternative forced-choice 5AFC, five-alternative forced-choice; 6AFC, six-alternative forced-choice.
Table 2. Overview of psychophysical taste tests suitable for children.

| Tool and author                          | Age (years) | Subtest                          | Presentation tastants                                        | Stimuli (number of solutions) | Concentration (mmol/l) | Strengths                                                                 | Weaknesses                                                                                                                                 |
|------------------------------------------|-------------|----------------------------------|-------------------------------------------------------------|------------------------------|------------------------|---------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------|
| Taste Detection Threshold test           | > 6 y       | DT, 2AFC staircase                | Taste solution in a cup (10 ml)                             | Sucrose (17)                 | 0.1 – 1000             | Extensive threshold procedure, protocol for preparation of taste solutions | Not commercially available, no normative data, long-lasting, not intended for clinical use or point-of-care testing |
| Joseph et al. 2021                      |             |                                  |                                                             | Sodium chloride (17)         | 0.1 – 1000             |                                                                           |                                                                                                                                            |
|                                          |             |                                  |                                                             | Monosodium glutamate (17)    | 0.1 – 1000             |                                                                           |                                                                                                                                            |
| Magic water test                         | 3 – 4       | DT, 2AFC decreasing concentrations| Taste solution in a cup (20 ml)                             | Sucrose (4)                  | 2.8 – 12.6             | Reliable, large sample size, test include a game and fairy tile, several concentrations of each taste quality (including umami) | Not commercially available, no normative data, restricted to specific age category, not intended for clinical use or point-of-care testing |
| Vennerød et al. 2017                    | n = 140     |                                  |                                                             | Sodium chloride (4)          | 5.8 – 16.8             |                                                                           |                                                                                                                                            |
|                                          |             |                                  |                                                             | Citric acid (4)              | 1.04 – 1.98            |                                                                           |                                                                                                                                            |
|                                          |             |                                  |                                                             | Quinine hydrochloride (4)    | 0.004 – 0.012          |                                                                           |                                                                                                                                            |
|                                          |             |                                  |                                                             | Monosodium glutamate (4)     | 1.0 – 2.9              |                                                                           |                                                                                                                                            |
| Taste sensitivity test                   | 5 – 12      | ID, 5AFC increasing concentrations| Pipette with taste solution (2 ml)                         | Sucrose (2)                  | 32, 320                | Reliable, quick, for clinical use                                         | Not commercially available, no normative data, small sample size, two concentrations of each taste quality |
| Majorana et al. 2012                    | n = 40      |                                  |                                                             | Sodium chloride (2)          | 32, 320                |                                                                           |                                                                                                                                            |
|                                          |             |                                  |                                                             | Citric acid (2)              | 1, 10                  |                                                                           |                                                                                                                                            |
|                                          |             |                                  |                                                             | Quinine hydrochloride (2)    | 0.032, 0.32            |                                                                           |                                                                                                                                            |
| European sensory perception test         | 3 – 10      | DT, 2AFC increasing               | Taste solution in a cup                                    | Sucrose (5)                  | 8.8 – 46.7             | Reliable, large sample size, test include a board                         | Not commercially available, no normative data, small sample size, two concentrations of each taste quality |
|                                          | n =         |                                  |                                                             |                              |                       |                                                                           |                                                                                                                                            |
| Study                          | Methodology                                                                 | Taste Test After Tongue Reduction | Electrogustometry | Screening Test for Gustatory Function |
|-------------------------------|------------------------------------------------------------------------------|----------------------------------|------------------|--------------------------------------|
| Knof et al. 2011              | Concentrations of each taste quality (including umami)                        | Caffeine (5)                     | Sodium chloride (5) | Sodium chloride (1)                   |
|                               | Cup (20 ml)                                                                  | 0.3 – 1.3                        | 3.4 – 27.4        | 0.1                                    |
|                               | Sodium chloride (5)                                                          | 0.6 – 9.5                        |                   | 0.1                                   |
|                               | Monosodium glutamate (5)                                                     |                                  |                   | 9.5                                   |
| Taste test after tongue reduction van der Horst et al. 2010 | Concentrations of each taste quality (including umami)                        | Sucrose (ID:1, RT: 3)            | Sodium chloride (ID:1, RT: 3)         | Sodium chloride (1)                   |
|                               | Cotton swab with taste solution                                              | 2000                             | 3500             | 180                                   |
|                               | ID: 2000, 20, 2                                                             | RT: 350                         | RT: 350, 35, 3.5 | 1000                                  |
|                               | ID: 200, 2, 0.2                                                             |                                  |                   | 3.2                                   |
|                               | Citric acid (ID:1, RT: 3)                                                    | 0.04                             |                   | 9                                     |
|                               | Quinine hydrochloride (ID:1, RT: 3)                                         | RT: 0.004, 0.0004, 0.00004       |                   | 1                                     |
| Electrogustometry Leung et al. 2009 | Electrical current between -6 dB up to 30 dB                                 | DT                               | EGM              | EGM is restricted to regional testing |
|                               | Commercially available, reliable, normative data, large sample size, for clinical use | NA                               |                   |                                       |
| Screening test for gustatory function Laing et al. 2008 | Normative data, large sample size, whole-mouth and regional part, for clinical use | ID, 3AFC                         | WM: taste solution in a cup (10 ml) R: cotton bud with taste solution | Reliability unknown, not commercially available, restricted to specific age category, one concentration of each taste quality (screening) |
|                               | Sucrose (1)                                                                  | WM: 360                          |                   |                                       |
|                               | Sodium chloride (1)                                                          | R: 1000                          |                   |                                       |
|                               | Citric acid (1)                                                              | WM: 180                          |                   |                                       |
|                               | Quinine hydrochloride (1)                                                    | R: 1000                          |                   |                                       |
| Taste sensitivity and aversion test | 3 – 6 | DT, 2AFC staircase | Taste solution in a cup (3 ml) | Sucrose (13) | 1.5 – 300 | Test is introduced as fairy tile, extensive threshold procedure | Reliability for urea is unstable, not commercially available, no normative data, small sample size, not intended for clinical use or point-of-care testing |
|-----------------------------------|------|-------------------|-----------------------------|--------------|-----------|-----------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------|
| Visser et al. 2000                | n = 45|                   |                             | Urea (15)    | 3.8 – 3000 |                                                                 |                                                                                                                                  |
| PROP threshold test               | 5 – 7 | DT, 2AFC staircase| Taste solution in a cup     | 6-n-propylthiouracil (15) | 0.006 – 3.2 | Extensive threshold procedure                                   | Reliability unknown, not commercially available, no normative data, small sample size, not intended for clinical use or point-of-care testing |
| Anliker et al. 1991               | n = 34|                   |                             |              |           |                                                                 |                                                                                                                                  |
| Taste sensitivity test            | 15   | RT, increasing concentrations | Taste solution in a cup (10 ml) | Sucrose (10) | 3.9 – 88.4 | Large sample size, extensive threshold procedure | Reliability unknown, not commercially available, no normative data, restricted to specific age category, not intended for clinical use or point-of-care testing |
| Nilsson and Holm 1983             | n = 100|                 |                             | Sodium chloride (10) | 2.8 – 62.5 |                                                                 |                                                                                                                                  |
|                                  |      |                   |                             | Citric acid (10) | 0.02 – 0.49 |                                                                 |                                                                                                                                  |
|                                  |      |                   |                             | Quinine hydrochloride (10) | 0.0014 – 0.0313 |                                                                 |                                                                                                                                  |

Abbreviations: DT, detection threshold; ID, taste identification; NA, not applicable; R, regional taste test; RT, recognition threshold; WM, whole mouth taste test; 2AFC, two-alternative forced-choice; 3AFC, three-alternative forced-choice; 5AFC, five-alternative forced-choice.