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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.

Key words: children, psychophysical test, self-report, taste, taste dysfunction

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 them. 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 (Saniasiaya et al. 2021). 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 amoxicillin (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 the 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, whereas 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 into 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 with 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 with 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 with taste dysfunction in the general pediatric population (Leung et al. 2009).

Childhood cancer and its treatment seem 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 with 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. 2021). 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 2 and 6 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 5 studies, taste function of children with obesity was compared with healthy controls. Although results seem to differ regarding individual taste qualities, the overall taste function of children with obesity is reported to be lower compared with controls in 3 studies (Overberg et al. 2012; Sauer et al. 2017; Mameli et al. 2019b). In addition, 47–77% 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

Table 1. Etiologies associated with taste dysfunction in childhood

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 with 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 2 chemotherapy cycles, showing higher thresholds for bitter taste among patients. Also, patients made more taste recognition errors compared with 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 1 month after BMT, but taste function was normalized 2 months after BMT for all patients.
Cancer *HSCT*	Majorana et al. 2015	Patients (*n* = 51)	3–12	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 4 stimuli. Six months after HSCT, taste function was normalized.
Cancer *Chemotherapy*	van den Brink et al. 2021	Patients (*n* = 31); controls (*n* = 24)	6–18	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 with before the start of that cycle. When compared with controls, patients had a higher sour taste score.
Cystic fibrosis	Laing et al. 2010	Patients (*n* = 42); controls (*n* = 42)	5–18	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 I	Mameli et al. 2019a	Patients (*n* = 31); controls (*n* = 31)	6–15	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 with 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	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	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.
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.

Table 1. Continued

Diagnosis	Author	Subjects (*n*)	Age (years)	Stimuli (number of solutions)	Taste test	Outcome
Obesity	Obrebowski 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 with 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 with controls. After intervention, sour taste scores improved whereas sweet taste scores deteriorated.
Obesity	Mameli et al. 2019b	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 with controls.
Obesity	Herz et al. 2020	Overweight/obese (*n* = 27); controls (*n* = 26)	12–16	Sucrose (4); sodium chloride (4); citric acid (4); quinine hydrochloride (4)	ID using Taste Strips, 5AFC	No significant differences in taste function were found between adolescents with overweight/obesity and controls.
Obesity *Lifestyle intervention*	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 with 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 with 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% and 50%, depending on the type of surgery, compared with 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.

with type 1 diabetes, however, showed a lower ability to correctly identify taste qualities compared with controls, especially for bitter and sour taste (Mameli et al. 2019a). 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 importance that a taste test can be easily administered, renders individual scores that can be compared with 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 4 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 4 taste tests and 1 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 were 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 2 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 8 different regions. The second part determines the correct identification of sweet, sour, salty, and bitter by using 3 solutions for each taste quality. Again, all 8 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 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 3 photographs (1 photo represents water in a glass, 2 represent tastants). During the whole-mouth test, the child has to sip and identify the 5 samples (sucrose, sodium chloride, citric acid, quinine hydrochloride, and purified water). During the regional test, the 4 tastants and a water sample are presented to each of 4 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 6 years, most children were able to understand instructions and complete the test.

Lastly, 1 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 9 items rated on a 5-point Likert scale of which 7 items address taste dysfunction and 2 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 the 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.

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 (Joseph et al. 2021)	>6	DT, 2AFC staircase	Taste solution in a cup (10 mL)	Sucrose (17) Sodium chloride (17) Monosodium glutamate (17)	0.1–1000 0.1–1000 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
Magic water test (Vennerød et al. 2017)	3–4 *n* = 140	DT, 2AFC decreasing concentrations	Taste solution in a cup (20 mL)	Sucrose (4) Sodium chloride (4) Citric acid (4) Quinine hydrochloride (4) Monosodium glutamate (4)	2.8–12.6 5.8–16.8 1.04–1.98 0.004–0.012 1.0–2.9	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
Taste sensitivity test (Majorana et al. 2012)	5–12 *n* = 40	ID, 5AFC increasing concentrations	Pipette with taste solution (2 mL)	Sucrose (2) Sodium chloride (2) Citric acid (2) Quinine hydrochloride (2)	32, 320 32, 320 1, 10 0.032, 0.32	Reliable, quick, for clinical use	Not commercially available, no normative data, small sample size, 2 concentrations of each taste quality
European sensory perception test (Knof et al. 2011)	3–10 *n* = 191	DT, 2AFC increasing concentrations	Taste solution in a cup (20 mL)	Sucrose (5) Sodium chloride (5) Caffeine (5) Monosodium glutamate (5)	8.8–46.7 3.4–27.4 0.3–1.3 0.6–9.5	Reliable, large sample size, test include a board game, several concentrations of each taste quality (including umami)	Not commercially available, no normative data, not intended for clinical use or point-of-care testing
Taste test after tongue reduction (van der Horst et al. 2010)	≥5 *n* = 10	ID, RT	Cotton swab with taste solution	Sucrose (ID:1, RT: 3) Sodium chloride (ID:1, RT: 3) Citric acid (ID:1, RT: 3) Quinine hydrochloride (ID:1, RT: 3)	ID: 2000 RT: 200, 20, 2 ID: 3500 RT: 350, 35, 3.5 ID: 200 RT: 20, 2, 0.2 ID: 0.04 RT: 0.004, 0.0004, 0.00004	Quick, threshold concentrations according to literature, for clinical use	Reliability unknown, small sample size, restricted to specific patient population
Electrogustometry (Leung et al. 2009)	4–18 *n* = 160	DT	EGM	NA	Electrical current between −6 dB up to 30 dB	Commercially available, reliable, normative data, large sample size, for clinical use	EGM is restricted to regional testing
Screening test for gustatory function (Laing et al. 2008)	5–7 *n* = 232	ID, 3AFC	WM: taste solution in a cup (10 mL) R: cotton bud with taste solution	Sucrose (1) Sodium chloride (1) Citric acid (1) Quinine hydrochloride (1)	WM: 360 R: 1000 WM: 180 R: 1000 WM: 9 R: 3.2 WM: 0.1 R: 1	Normative data, large sample size, whole-mouth, and regional part, for clinical use	Reliability unknown, not commercially available, restricted to specific age category, 1 concentration of each taste quality (screening)
Taste sensitivity and aversion test (Visser et al. 2000)	3–6 *n* = 45	DT, 2AFC staircase	Taste solution in a cup (3 mL)	Sucrose (13) Urea (15)	1.5–300 3.8–3000	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

Table 2. Continued

Tool and author	Age (years)	Subtest	Presentation tastants	Stimuli (number of solutions)	Concentration (mmol/l)	Strengths	Weaknesses
PROP threshold test (Anliker et al. 1991)	5–7 n = 34	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
Taste sensitivity test (Nilsson and Holm 1983)	15 n = 100	RT, increasing concentrations	Taste solution in a cup (10 mL)	Sucrose (10) Sodium chloride (10) Citric acid (10) Quinine hydrochloride (10)	3.9–88.4 2.8–62.5 0.02–0.49 0.0014–0.0313	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

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.

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 6 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 min 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 with 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), 5 concentration steps are investigated. Another taste test focuses on pre-schoolers (3–4 years) and uses a fairy tale to introduce 5 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, 2 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 3 of the 5 taste substances, whereas 6- and 7-year-olds are expected to identify 4 substances. However, the screening test itself has not been used in later studies. Instead, an extended identification task including 5 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 3 concentrations of each tastant, and older children at least 4 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. 2019a, 2019b; Herz et al. 2020; van den Brink et al. 2021; 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, 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 the quality of life in pediatric patients. Furthermore, as taste dysfunction has important implications for food intake in the short term and for the development of dietary habits and food preferences in 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.

Author contributions

Mirjam van den Brink conceptualized the study, performed the literature search, selected articles, drafted the initial manuscript, and revised the manuscript. Irene IJpma, Wim Tissing, and Remco Havermans critically reviewed and revised the manuscript for important intellectual content. All authors approved the final manuscript as submitted and agree to be accountable for all aspects of the work.

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Conflict of interest

The authors have no conflicts of interest relevant to this article to disclose.

Consent statement

Not applicable because human subjects were not involved in this review.

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