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RHINOLOGY: TASTE AND SMELL DISORDERS (C PHILPOTT, SECTION EDITOR)

Psychophysical Testing in Chemosensory Disorders

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Abstract
Purpose of Review To provide an overview of psychophysical testing in olfaction and gustation.
Recent Findings Subjective patient report correlates poorly with objective assessment of olfaction and gustation. It is therefore important that clinicians and researchers perform psychophysical testing during chemosensory assessment. There are several validated psychophysical tests of olfaction and gustation, with ongoing developments accelerated by the COVID-19 pandemic. These tests have been culturally and linguistically adapted globally. Screening tests have been developed with careful consideration to distinguish normosmics from those with olfactory dysfunction.
Summary Validated chemosensory tools are available for use by the clinician to support screening, diagnosis, or monitoring. There are promising advances in self-assessment and screening that provide avenues for the development of a standardised pathway for identification and formal assessment of patients with smell and taste disorders.

Keywords Chemosensory assessment · Olfactory and gustatory assessment and screening · Psychophysical testing and assessment

Introduction

Of the special senses, chemosensory disorders have traditionally been neglected, in both research and clinical settings. The COVID-19 pandemic raised awareness of both quantitative (hyposmia (partial loss of smell) and anosmia (total loss)) and qualitative (parosmia (distorted smell) and phantosmia (hallucination of smell)) impairment as a consequence of viral infection, but post-infectious olfactory dysfunction is not a new phenomenon and one of many different underlying aetiologies.

Human olfaction is an important sense required for social and environmental navigation. Olfactory dysfunction (OD) affects mood and social interactions and can be detrimental to health due to failure to recognise potentially dangerous situations such as smoke and putrid foods. It is a recognised early marker of neurodegenerative disorders such as Alzheimer's and Parkinson's diseases and is linked with mortality in older adults [1–3]. Anosmia is estimated to affect approximately 5% of the general population, whilst the overall prevalence of OD is thought to be around 22% [4, 5].

Olfaction comprises two pathways: orthonasal olfaction describes the sensation of smell with stimuli from the external environment, whilst retronasal olfaction describes stimuli from the naso- and oropharynx during eating. These pathways merge onto the olfactory neuroepithelium, found within the confines of the olfactory cleft. Here, odorants activate olfactory receptors found on the dendritic cilia of olfactory receptor neurons, bipolar neurons which extend axons through the cribriform plate and to the olfactory bulb (OB). Collectively, such axons comprise the olfactory nerve (cranial nerve I). The OB is the first relay station within the central olfactory network. It is thought to help encode odour quality, though in a small number of people, olfaction is

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possible in the absence of demonstrable OBs [5]. Upstream, olfaction is processed in the primary and secondary olfactory networks, which considerably overlap structures of the limbic system [6].

Otorhinolaryngologists frequently describe disorders of olfaction according to the anatomical location of pathology, in a way analogous to hearing loss, conductive, sensorineural, or central. However, there is overlap in pathological distribution in several conditions. For example, OD due to chronic rhinosinusitis may involve mechanical obstruction of odorants to the olfactory cleft due to polyps [7], temporary interference with olfactory receptor binding due to inflammation [8, 9], metaplastic epithelial change from olfactory to respiratory [10], changes in OB, and higher olfactory network structures [11–14]. For this reason, the Position Paper on Olfactory Dysfunction recommends description of OD according to underlying aetiology. Where there is no obvious underlying aetiology despite thorough investigation, these cases are classified as idiopathic [15••]. The types of olfactory dysfunction are summarised in Table 1.

Gustation occurs through stimulation of taste receptor cells found within taste buds. Taste buds are present in the papillae of the tongue, soft palate, epiglottis, pharynx, and larynx. Stimuli are grouped into sweet, salty, sour, bitter, and umami. Following activation, taste receptor cells transmit signals to the central taste network via the facial and glossopharyngeal nerves. Combined, gustation, retronasal olfaction, and trigeminal activation (which impart chemesthetic sensations such as the burn of capsaicin) create the flavour percept. Pure disorders of gustation are rare, and patients complaining of altered 'taste' are often describing impaired flavour perception due to disorders of retronasal olfaction.

Chemosensory assessment includes a full head and neck examination including nasendoscopy, followed by further comprehensive investigation, including psychophysical olfactory and gustatory tests. Formal assessment allows patients to understand the severity of their condition, clinicians to select and assess the efficacy of treatments, and can identify malingerers. However, formal assessment in this way is not universally performed, perhaps due to the availability of psychophysical test kits and time required. In light of this, prior to discussing psychophysical tests, subjective assessment will be briefly addressed.

Subjective Assessment

Subjective chemosensory assessment can be performed using various tools, including medical history alone, anchored scales, or Likert type questions. Such tools have been developed specifically for use in OD. However, many can be found embedded within questionnaires targeted at conditions that affect chemosensation, such as chronic rhinosinusitis (e.g. the SNOT-22).

An increasing body of evidence suggests that subjective reporting correlates poorly with more objective measures, such as psychophysical tests. Regarding olfaction, studies have demonstrated poor correlation with psychophysical tools in both healthy subjects [16] and patient populations [17, 18, 19•]. Philpott and colleagues found that only 28% of patients presenting to a UK-based rhinology clinic were able to accurately report their olfactory abilities [20]. Poor accuracy of self-reported OD has also been demonstrated in the context of population work–Seubert and colleagues demonstrated a sensitivity of just 31% [21]. Whilst some studies have demonstrated decreasing accuracy with age [22], others have not [23]. For this reason, it is recommended that subjective assessment be performed alongside another method, such as psychophysical testing [15••].

Where self-assessment is used, validated questionnaires are preferable to patient report alone. The Questionnaire of Olfactory Disorders (QOD) comprises 58 items and is split into 3 separate domains: negative statements (NS), positive statements (PS), coping strategies and socially desired statements. The QOD-NS assesses OD in daily life activities and scenarios and correlates with candidates with a lower psychophysical score (Sniffin' Sticks composite 'TDI' score). The shortened QOD-NS and the Self-Reported Mini Olfactory Questionnaire (Self-MOQ) are validated for use in the clinical setting [24].

Wehling et al. highlight the importance of how we ask about olfaction and specifically that more accurate results are achieved from targeted self-assessment (such as comparison to the general public or comparison to self at younger age). In anosmics, sensitivity and specificity increase when older adults are asked to describe their sense of smell now, compared to when they were younger [25]. The discrepancy in subjective and objective assessment of olfaction could be due to lifetime exposure to stimuli (such as consumption of herbs and spices) or personality traits. There is evidence to suggest that if certain scents have negative associations, then perhaps there is a lower threshold for detection of this odour and the individual perceives themselves to have 'above average' sense of smell [26].

Whilst there are validated questionnaires in practice to assess olfactory disorders, there are no such validated questionnaires for the sense of taste. This is due to the complexity of perception of taste, the interlinked dependence on olfaction, and the low prevalence of isolated taste disorders.

Psychophysical Testing

Psychophysical testing involves the presentation of a sensory stimulus (in chemosensation–an odour, tastant, or trigeminal stimulant) to a subject, who is scored based on a particular aspect of their perception of that stimulus.

Table 1 Types of olfactory dysfunction, pathology, and natural history

Type of olfactory dysfunction	Pathophysiology	Typical history
Sinonasal–e.g. chronic rhinosinusitis with polyps	Mechanical obstruction of the olfactory cleft, temporary interference with olfactory receptor binding due to inflammation, eventual neuroepithelial remodelling/CNS changes	Gradual onset fluctuates over time. Typically improves with adequate treatment (nasal/systemic steroids). Not commonly associated with parosmia. Most of these patients present to GP and are managed in the community or by otolaryngologists
Post-infectious olfactory dysfunction (PIOD)	Viral common pathogens include RSV, parvovirus and HIV Long-term inflammation causes neuroepithelial remodelling to respiratory type epithelium	Sudden onset often associated with parosmia, little fluctuation 1 in 3 recovery of psychosensory scores over 14 months. Viral common pathogens include common cold, influenza, and HIV [68]
Post-traumatic olfactory dysfunction (PTOD)	Severing of olfactory nerve filament or damage due to primary or secondary CNS injury	Sudden onset or delayed (may be related to noticing OD when back in normal environment) Fluctuation uncommon, phantosmia and parosmia are common Recovery, although less common than post-infectious, can be up to 30% depending on severity
Neurodegenerative causes–e.g. Alzheimer's (AD) and Parkinson's disease (PD)	Neurofibrile changes in the OB and higher olfactory network Lewy bodies deposit in the olfactory tract, OB, and anterior olfactory nucleus [69]	Insidious onset, unlikely to see improvement
Age-related	Loss of and replacement of olfactory neurons with respiratory epithelium. Decreased basal cell proliferation Decrease of interneurons in OB with reduced activity in olfactory cortex	Insidious onset, unlikely to see improvement. Impairment in 62% in people over 80. NSHAP study showed OD as a 5-year mortality predictor [49]
Other medication/toxin exposure/iatrogenic	Altered receptor function by binding G-protein coupling or affecting calcium or sodium channel activity	Sudden onset that is mostly alleviated by ceasing medication or exposure. Can persist in some cases requiring treatment. Can have medico-legal implications [70]

All psychophysical tests should be accurate and reliable. Those used clinically should also be cost-effective and time-efficient. Both research and clinical tests have been developed which target orthonasal olfaction, retronasal olfaction, and gustation. Trigeminal function is infrequently assessed outside of the research environment.

Psychophysical tests can be broadly divided into threshold and suprathreshold tests. Threshold tests aim to determine the minimum concentration of a stimulus that can be perceived by the subject. Suprathreshold tests aim to test some qualitative aspect of a perceptible stimulus (for example, the identity of an odour, its similarity to another odour, its pleasantness, or its familiarity). Stimuli used for suprathreshold testing are of sufficient strength that they should be perceived by unimpaired subjects. However, in patients with moderate to severe dysfunction, suprathreshold tests also crudely test threshold.

With regard to orthonasal olfactory testing, the most commonly used tools include one or more of the following subsets:

1. Identification (I), where subjects are asked to identify an odour, usually as a forced-choice from a number of distractors.
2. Threshold (T), the most dilute concentration of an odour that can be perceived by the subject. Again, this may be a forced-choice from odourless distractors.
3. Discrimination (D), where subjects are asked to differentiate between different odours.

Whilst some commonly used and well-validated tools only test one of these aspects (most frequently odour identification, summary available in Table 2), evidence suggests that the pattern of subtest results may reflect underlying disease aetiology [27–29]. It would appear that tests of odour threshold may preferentially represent the peripheral olfactory apparatus (i.e. the nose and olfactory neuroepithelium), whilst suprathreshold tests best reflect central olfactory function (i.e. the brain) [27]. For this reason, tools such as the Sniffin' Sticks which test both threshold and suprathreshold function may have some diagnostic advantage over those that do not. This must, however, be weighed against the additional time needed for their administration.

When considering the use of odour identification, it is important to note that such tests are culturally specific. For example, patients from Germany may be familiar with the smell of sauerkraut, which is included in the Sniffin' Sticks, whilst those from other parts of Europe, the Middle East, or Far East may not. Accordingly, identification tests must be validated for the local population, with cultural adaptation as required. Such adaptation may involve alteration of test vocabulary or stimuli used. This has been done for both the Sniffin' Sticks identification subtest and SIT. For example, Iran developed the Iran-SIT by changing a portion of the sample odours and discriminators based on familiar scents identified in an Iranian student population [30], whilst a validated adaptation of the Sniffin' Sticks for the UK altered the descriptors alone allowing assessment flexibility by adapting test software only [31]. Similar validated alternatives have been developed in Spain and Greece [32, 33]. Practically, in a multicultural society, the clinician must ensure that any identification tests used are validated for the cultural background of the patient being tested. Assessment of identification alone does not always require trained personnel to administer the test, lending itself to testing in busy clinical settings and screening.

Threshold testing is not culturally specific. Furthermore, it has the added benefit of using a single odorant with definable concentration steps–advantageous where international standardisation is required. Administration of threshold testing usually requires trained personnel to obtain the most sensitive results [34].

Discrimination testing is not culturally specific, though subjects may find some strategic advantage where they are able to identify the test odours being used.

Orthonasal test odours are most often administered through pen-like dispensing devices, odour bottles, microencapsulation, or 'peel-and-burst' delivery systems. Such systems can easily be used in office environments. Olfactometers are machines that deliver odorants more precisely, usually embedded in high-flow, warmed, and humidified airstreams. Such olfactometers are mostly used in research settings for electrophysiological or functional imaging work, as opposed to psychophysical testing, given the time, expense, and expertise required for their use. An exception is the T&T olfactometer, which is used clinically for threshold and identification testing in Japan–indeed this is the only validated test that Japanese physicians can claim on medical insurance [35].

When using orthonasal olfactory tests to diagnose quantitative olfactory dysfunction, reference must be made to normative data for the tool being used. Diagnosis of hyposmia or functional anosmia may be age and sex adjusted (function decreases with age and male sex), though is often made in reference to a young, healthy population. Furthermore, where a psychophysical tool is used to assess change in function, e.g. due to disease progression or treatment intervention, this should be done with reference to the minimally important clinical difference (MCID) for that tool. When choosing an appropriate test for clinical and research use, the availability of such data must be considered. Amongst others, such data is available for the Sniffin' Sticks and SIT.

Table 2 A summary of validated olfactory and gustatory assessments

Orthonasal test	Components	Duration	References
Sniffin' Sticks extended test	• Combined identification, threshold and discrimination testing (composite 'TDI') • Translated and adapted internationally • Test–retest reliability $r = 0.61$ (threshold), $r = 0.54$ (discrimination), $r = 0.73$ (identification)	25–30 min	Haehner et al. [71], Hummel et al. [72]
University of Pennsylvania Smell Identification Test	• 40 odorants in microencapsulated scratch and sniff identification testing • Self-administered, translated, and adapted internationally • Test–retest reliability $r = 0.90$	10–20 min	Doty et al. [73, 74]
Combined olfactory test	• 9 substances, combined threshold and identification testing • Trigeminal assessment using ammonia • Test–retest reliability $r = 0.87$	5–10 min	Robson et al. [75], Lam et al. [76]
Snap & Sniff	• Single staircase threshold detection assessment • 20 rechargeable smell wands increasing concentrations phenyl ethyl alcohol (PEA) • Test–retest reliability $r = 0.88$ (repeated after 5 h)	< 10 min	Doty et al. [77]
Sniffing dead system	• 7-mm beads inserted in a device and pierced to release concentrations of PEA • Threshold detection testing of geriatric population, single-use • Good correlation with threshold subset of validated Korean test	5–10 min	Min et al. [78]
San Diego Odor Identification Test (SDOIT)	• Eight-item identification test using items found at home, wrapped in gauze • Test–retest $r = 0.86$	Not stated	Krantz et al. [79]
Barcelona Smell Test (BAST-24)	• 24 odours, 4 odours (vinegar, formalin, mustard, ammonia) to assess trigeminal nerve • Assessment of odour 'detection' and forced-choice identification assessment	20 min	Cardesín et al. [80]
Scandinavian Odour-Identification Test (SOIT)	• 16 odours including ammonia to assess trigeminal nerve • Forced-choice identification task • Test–retest $r = 0.79$	15 min	Nordin et al. [81]
Toyota and Takagi (T&T) olfactometer	• 5 test odorants diluted at 8 log-step concentrations • Assessed for detection and recognition threshold	Not stated	Takagi [82]
Smell diskettes	• 8 diskettes used in perfume and tasting industry • Identification, triple forced-choice • 6–12-month shelf life • 99% specific for normosmia	< 5 min	Briner et al. [83]
Screening test	**Components**	**Duration**	**Reference**
Sniffin' Sticks–screening identification	• 12 odours, identification forced-choice encapsulated pens • Test–retest $r = 0.77$ • 1-year shelf life, < $100 for one set	4 min	Hummel et al. [84]
Q-Sticks	• 3-item felt tips • Cut-off score < 2 sensitivity 92%, specificity 92%	Not stated	Sorokowska et al. [51]
Cross-Cultural Smell Identification Test (CCSIT)	• 12 odours, shortened from UPSIT • Identification testing forced-choice, cross-culturally adapted for Europe and Asia • Test–retest reliability $r = 0.77$, compared to $r = 0.92$ in full UPSIT battery	< 5 min	Doty et al. [85], Joseph et al. [86]
Pocket Smell Test/Q-SIT	• Shortened 3-item UPSIT • Single-use, identification forced-choice scratch n sniff • Cut-off ≤ 2, sensitivity 82%, 63% specificity for detection of OD	5 min	Joseph et al. [86], Jackmann et al. [52]

Table 2 (continued)

Screening test	Components	Duration	Reference
Short ETOC (European Test of Olfactory Capabilities)	• 6-item version, small glass vials • Combined discrimination and identification forced-choice • 84% accurate (linear discriminant analysis) • Tested in France, Sweden, Netherlands, Switzerland • Reusable, portable, self-administration option	5–10 min	Thomas-Danguin et al. [87], Joussain et al. [88]
SCENTinel 1.0	• Lift n' smell disposable cards • Combined identification, detection, and discrimination of intensity • Forced-choice identification, given second chance with reduced options if incorrect in first instance	2 min	Parma et al. [67•]
Nez du vin	• 6 commonly recognised odours out of 54 used in wine tasting. Cotton bud saturated in solvent stored in a refrigerated polythene bag, 2-week shelf life • Identification, forced-choice • UPSIT correlation coefficient $r = 0.79$	2 min	McMahon et al. [89]
Alcohol Sniff Test (AST)	• Folded 70% isopropyl alcohol in sachets, readily available in hospital, single-use • Threshold testing starting at 30 cm, decreasing by 1 cm	5 min	Davidson et al. [90]
Retronasal test	**Components**	**Duration**	**Reference**
Candy Smell Test	• 23 aromatised sorbitol candies assessment of retronasal olfactory function (shortened version for screening 7 aromas) • Pill shaped, consumable, single-use • Test–retest $r = 0.75$	5–10 min	Haxel et al. [41], Renner et al. [43]
Q-powders	• Retronasal assessment using single-use tasteless powders • 3 odours, cut-off score of 2, 84% sensitivity, 64.9% specificity	5 min	Pieniak et al. [91]
Retronasal testing in seven European countries	• Identification of 20 grocery-store available non-sticky or granular powders • Samples assessed for consistent identification across 7 European countries • Cut-off score of 12 for anosmia, 97% sensitivity, 87% specificity	20 min	Croy et al. [47]
Taste tests	**Components**	**Time**	**Reference**
Taste tablets	• 28 tablets of sweet, sour, salty, and bitter at varying concentrations • Threshold assessment and recognition • Correlation coefficient $r = 0.66$ compared to three-drop taste testing. Test–retest $r = 0.69$	15–20 min	Ahne et al. [92]
Taste strips	• Regional testing of threshold and identification of 18 strips of 4 concentrations of sweet, sour, salty, bitter, and 2 blanks • Long shelf life • Test–retest $r = 0.68$	8 min	Mueller et al. [57]
Three-drop taste	• Threshold assessment of sweet, sour, salty, and bitter via reverse staircase method • Test–retest reliability for threshold scores $r = 0.8$ (sweet), $r = 0.73$ (salty), $r = 0.76$ (sour), $r = 0.74$ (bitter) but lower re-test recognition scores • Can be used for regional testing	Not stated	Fjaeldstad et al. [58]

Orthonasal Olfactory Testing in Children

Several of the previously described psychophysical tests are suitable for the paediatric population, aged as low as 5 years old. Specific adaptations for children include the 'U-sniff', adapted from the Sniffin' Sticks, and the paediatric Barcelona Olfaction Test (pBOT-6) [36, 37].

Orthonasal Olfactory Testing in Qualitative OD

Until recently, there have been no specific psychophysical tests available for the diagnosis of qualitative OD. Accordingly, these conditions are diagnosed using careful medical history. However, Liu and colleagues recently described the first psychophysical tool for the diagnosis of parosmia–an adaptation of the Sniffin' Sticks test–the 'Sniffin' Sticks Parosmia Test–SSParoT' [38]. This tool uses metrics based on the hedonic valence of different odours. It has been validated in normosmics, but has not yet been trialled in patients and the MCID is awaited.

Retronasal Olfactory Testing

As mentioned above, impaired retronasal olfactory function is often construed as impaired 'taste' [39]. As a first step in the assessment of such complaints, careful questioning should aim to separate the two. Where this is not possible, or where they may co-occur (for example, in COVID-19-related OD), both retronasal and gustatory testing should be performed [40].

Most commonly, retronasal olfactory testing is performed using flavoured solutions, powders or candies [41–44] (see Table 2). These tests are limited by the 'taste' component of such stimuli (e.g. the relative bitterness of coffee powder may aid in its identification). Therefore, 'tasteless' powders have been developed [45], as well as delivery systems that bypass the tongue and oral mucosa [46]. As for orthonasal testing, similar issues with cultural-specific identification persist with retronasal testing, and a study across seven European countries has accounted for this in the development of a simple retronasal assessment [47]. Post hoc analysis also demonstrated less variation in identification scores related to increasing age compared to orthonasal combined olfactory testing suggesting less decline in retronasal olfaction with age [47, 48].

Olfactory Screening Tests

Population-based assessment of olfaction has been performed as part of larger epidemiological studies, such as the National Social Life Health and Aging Project (NSHAP) of the USA [49]. Validated, accurate, and reliable screening methods are required for such large-scale testing. Where subjects with OD are identified, they should be referred to appropriate centres for full chemosensory testing.

Several olfactory tools have been modified for screening purposes with reduced administration time, some lending themselves to self-administration (summarised in Table 2). Although most tests are shortened versions of the parent odour identification subtest, threshold testing lends itself well to screening [50]. As mentioned earlier, threshold does not require semantic recall and can therefore be used internationally at all ages.

Very short tests which employ only a few odours have been developed. These have the advantage of very fast testing times (useful in population studies), but only allow for the separation of OD from normosmia, not the quantification of OD severity. As above, any subjects with OD identified in this way should be referred for full testing. Such tests include the 'Q-Sticks', a 3-item test derived from the Sniffin' Sticks identification subtest [51] and the 'Pocket Smell Test' or 'Quick Smell Identification Test, Q-SIT' which are both derived from the SIT [52].

Careful consideration needs to be taken when reducing the number of stimuli in screening. Lötsch and colleagues performed analysis of a cohort that was assessed using Sniffin' Sticks to identify the most valuable odours that would differentiate normosmics from anosmics. The most reliable scents were determined by an 'odour specificity score' which calculated the difference between the proportion of normosmics and the proportion of anosmics that correctly identified a scent. Whilst peppermint, clove, and fish odour are most frequently correctly identified by the normosmic population, peppermint and clove were also correctly identified by more than 25% of the anosmic population, probably due to the activation of the trigeminal pathway, and exceeding the likelihood of these scents being identified by chance in a forced-choice paradigm. The most reliable scent that discriminated normosmics from anosmics was cinnamon (identified correctly by 87.2% of normosmics and by 14.75% of anosmics). This was followed by banana and fish odour. Correct identification of all 3 odours is 80% sensitive and 84% specific in identifying normosmia [53].

Assessment of Gustation

Gustation can be affected by infection, medication, salivary flow, surgical trauma to the chorda tympani during middle ear surgery, or radiotherapy for the treatment of head and neck cancers. This can have a negative impact on quality of life and nutrition.

As mentioned, although impaired retronasal olfaction is often reported as impaired 'taste', there is a small population with isolated taste disorders (ITD) [54]. Accordingly,

several studies suggest poor correlation between self-reported dysgeusia and formal assessment. Retrospective studies in Germany and Denmark reported that only 3.4–4% of patients who presented with impaired taste had an isolated taste disorder, with the remainder having some degree of OD [55, 56]. A study on patients with subjective gustatory complaints referred by ENT specialists prior to chemosensory assessment also concluded that patients who reported subjective gustatory dysfunction had a measurable olfactory disorder, though they had reported their sense of smell to be subjectively normal [19•].

Psychophysical gustatory testing uses stimuli delivered in the form of liquid, tablets or powder that assess whole-mouth taste, or taste strips which can be used to assess either whole-mouth or regional gustation [57], the latter being important where chorda tympani damage is suspected. Full gustatory testing is most commonly performed using liquid taste drops or taste strips, both of which assess threshold and identification of sweet, salty, sour, and bitter (umami is not commonly tested as it is poorly identified even in unimpaired subjects). Taste strips are advantageous for their ease of use, long shelf life, and precision of regional application. However, these do not employ serial dilution steps. New liquid tests have been developed which aim to both achieve regional application and stepwise concentration steps, so enabling more precise assessment of disease progression or treatment effects [58] (summary in Table 2). Again, tests used in clinical or research environments must be validated, with normative data available for diagnosis of impairment and determination of MCID. In practice, however, screening for whole-mouth identification of sweet, salty, sour, and bitter is most frequently performed during chemosensory assessment, with full gustatory testing limited to those with abnormal screening results. Where a patient presents with abnormal taste but has normal gustatory screening, clinicians should consider retronasal OD and appropriate olfactory testing [59].

Electrogustometry uses an electric current to stimulate the taste sensation of sweet, sour, salty, and bitter when applied to the surface of the tongue. It is useful in assessing for gustatory regional function. It is quick to administer and can test in extremes of age successfully but requires specialist equipment and training [60]; there are reports of false positives due to trigeminal stimulation [61]. Therefore, its use is mainly limited to research settings.

Novel Home Tests

In 2020, altered smell and taste were listed as official symptoms of COVID-19 by the World Health Organization. Since this time, it is thought that over 300 million people have experienced some degree of acute or chronic chemosensory dysfunction. The pandemic has created a unique scenario of social isolation and limitation of face-to-face assessment by clinicians due to infection control. This has required adaptations in practice including telecommunication and development of psychophysical assessment tools that can be performed independently. These comprise tests that can be entirely prepared at home and administered by the subject, or which are cheap enough and small enough to be easily delivered to the subject's home for self-administration. Screening versions of the SIT, such as the 'Q-SIT' or 'Pocket Smell Test' could be included in this category of test. Previous screening tests used in population-based studies, such as that used in the OLFACAT study, could also be repurposed for such use [62]. Similar to screening scenarios–where detailed chemosensory information is required–subjects should undergo full testing.

Early in the COVID-19 pandemic, an Italian study investigated home-isolating health workers to prepare their own olfactory threshold, discrimination, identification, and gustatory tests. Subjects were instructed to locate 7 household items for identification testing (orange, pepper, soap, wine, chocolate, toothpaste, with substitutes) and to prepare dilutions of 40% ethanol using drinking water as a control for threshold testing. To assess taste, they prepared standardised solutions of table salt, sugar, lemon juice, and decaffeinated coffee. They were assessed over the telephone by an operator and their scores were converted to a 'composite score', which was compared to the Connecticut Chemosensory Research Centre (CCRC) orthonasal olfaction test performed the following day. The study showed a tendency to underestimate threshold scoring and over-estimate discrimination scoring when assessing at home [63]. Whilst the identification and taste tests can be prepared at home, it is not clearly stated how these subjects obtained 40% ethanol for threshold testing. This study was developed in the early stages of the COVID-19 pandemic with limitations of isolation and lockdown, highlighting the difficulty in remote objective chemosensory assessment, especially standardised threshold testing. It was limited by the selection bias of compliant subjects and the potential for error during the preparation of the test.

Gupta and colleagues developed a home test from 7 commonly available household items with 7 possible substitutes, the Novel Anosmia Screening at Leisure (NASAL-7), as well as a shortened 3-item NASAL-3 version. Both NASAL-7 and NASAL-3 correlated moderately with the UPSIT, $r = 0.484$ and $r = 0.404$, respectively. Scoring ≤ 7 on the NASAL-7 test discriminated anosmic patients from non-anosmics with a sensitivity of 70% and specificity of 53%, whilst scoring ≤ 2 on the NASAL-3 had a sensitivity and specificity of 57% and 78%, respectively. The study was limited by the fact that the participants performed the SIT at home and the screening results were validated against unsupervised psychophysical test scores [64].

In the USA, Patel et al. evaluated the 'U-smell-It' test, 5 odours on a single 'scratch and sniff' card based on the NIH Toolbox, as a cost-effective screening test for COVID-19, by comparing the detection of OD to a positive PCR (polymerase chain reaction) test. Using a cut-off score ≤ 4 in the symptomatic cohort, sensitivity was 85% and specificity was 39%. A cut-off ≤ 2 yielded 40% sensitivity with 89% specificity, demonstrating the importance of determining the purpose of an assessment for screening when determining cut-off scores [65].

The Adaptive Olfactory Measure of Threshold (ArOMa-T) was designed to determine odour threshold based on an adaptive Bayesian algorithm, using an app to direct the candidate without the need for an assessor. The study was performed during the COVID-19 pandemic, at an outdoor festival in the USA. Using a folded card with 17 'peel and burst' ovals that released either 'no odour' or a range of concentrations of PEA (-4.5 $\log_{10}$ to 0 in increments of 0.5 $\log_{10}$), including duplicates to increase accuracy and reduce the incidence of false identifications of blank scents. The app directed each candidate to peel and sniff a numbered disc based on their ability to detect the previous sample. The ArOMa-T took an average of 3 min to complete in the open-air and had a test–retest reliability of $r = 0.66$ [66]. The study does not describe correlation with validated tests, but this test design is promising in that it could screen for detection thresholds in at reduced time and cost without the need for trained personnel.

The development of the SCENTinel 1.0 is the only screening test to assess all three domains of identification, threshold, and discrimination. The assessment design uses 'Lift n' Smell' technology where the adhesive releases an odour and the subject selects the strongest odour, rates its intensity on a visual analogue scale, and identifies it amongst provided distractors. The composite subtest score produces the greatest accuracy in discriminating between normosmic and anosmics [67•].

Conclusion

Given the disparity between subjective patient report and psychophysical testing, we would encourage clinicians and researchers to adopt validated chemosensory tools when assessing olfaction and gustation, either for diagnostic or monitoring purposes. The ongoing COVID-19 pandemic has catalysed the development of new and convenient 'home' tools. Where such tools are accurate, reliable, and are supported by sufficient normative data, their widespread use could improve patient care, the quality of chemosensory research and thereby support the development of new, and much needed treatments.

Declarations

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

Conflict of Interest The authors declare no competing interests.

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Papers of particular interest, published recently, have been highlighted as:
• Of importance
•• Of major importance

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