A systematic review of olfactory related questionnaires and scales*

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Abstract

Purpose: Although neglected by science for a long time, the sense of olfaction has received increasing attention from research areas including psychology, neuroscience, clinical medicine and nutrition. With the rise of psychophysical and neuroimaging research into olfaction, psychometric tools (e.g. questionnaires and scales) are the basis for the quantitative exploration of inter-individual variability regarding olfactory related responses. The current systematic review is to summarize existing olfaction related questionnaires and/or scales.

Methods: Peer-reviewed literature on scales and questionnaires related to perception of odors were searched from online databases (PubMed, Web of Science and PsycINFO). Twenty-one articles that meet the following criteria were included in the review: "human species", "no physical odor stimuli" and "describing the original development of the tool", and "with specific focus on olfaction or odor related responses or behaviors". The psychometric properties, advantages and possible disadvantages were discussed.

Results: Existing psychometric measures focus on various aspects of olfactory related responses and behaviors, including affective experiences of odor perception, awareness and attitude towards olfaction, olfactory function and the quality of life change due to olfactory dysfunction, and the ability to create vivid mental odor images. While most of them have been tested to have good reliability and validity, some were relatively time-consuming due to the number of questionnaire items. Besides, although many measures have been used in clinical populations, few have provided information on the predictive validity regarding effectiveness of clinical intervention on changes of certain responses or behaviors.

Summary: The current review provides an overview of olfactory related questionnaires and scales, highlighting the emotional and affective impact of olfaction and the impact on quality of life due to olfactory dysfunction. With growing interest in olfaction as an important sense, the development and use of psychometrically sound measurements in conjunction with objective assessments will advance our understanding of human olfaction and olfactory dysfunction. The review provides a guide for researchers and clinicians alike to select olfactory scales suitable for olfactory research with different experimental purposes and specific samples.

Key words: olfaction, odor, questionnaire, scale, systematic review, psychometrics

Introduction

Having received relatively little attention over the last 100 years, recent evidence suggests that the human sense of smell is not a negligible entity [(1)]. It is now clear that olfaction has both the hedonic/defense functions and the social functions, influencing behaviors such as food ingestion, harm avoidance, and social communication [(2, 3)]. Compared to other senses (e.g. vision or audition), olfaction has a unique intimacy with emotions [(4)]. The olfactory neuroanatomy is intertwined with the brain limbic system which is considered as the primary emotion areas [(5)]. Potent affective responses (e.g. disgust or pleasantness), arise spontaneously in the presence of most olfactory stimuli [(6)]. Recent evidence further promotes the idea that affective valence represents the dominant dimension in olfactory perception, and

affective experience is the primary behavioral correlate of odor properties [7, 8]. From a psychological point of view, emotion is a structural element that accompanies and characterizes olfaction and also functionally related to olfaction [9]. Emotions can arise from odors and emotions can also influence odor perception [10-12].

In general, olfactory function covers a wide spectrum that includes anosmia (the sense of smell is lost completely or reduced to the extent that the patient has no function that would be useful in daily life), hyposmia (the sense of smell is partially reduced), normosmia (normal olfactory function), and hyperosmia (increased olfactory acuity) [13]. Besides, parosmia (distorted odor perceptions in the presence of an odor source) and phantosmia (odor percepts in the absence of an odor) describe qualitative olfactory dysfunction [14]. It has been suggested that olfactory dysfunction is a common problem affecting 20% to 62.5% of certain populations [15-17]. Olfactory dysfunction has a significant impact on quality of life (QoL) [18]. Further, it has been argued that both reduced olfactory performance (anosmia/hyposmia) as well as hyperosmia are associated with altered affective or emotional processing. Olfactory dysfunction had been shown to be a biomarker for affective disorders and neurodegenerative diseases, such as depression [19, 20], schizophrenia [21], eating disorders [22], or dementia [21, 23, 24], and also regarded as an early indicator for COVID-19 infection [25].

The last two decades have witnessed an increasing interest in the field of human olfaction. There is high inter-individual variability in olfactory performance [26], affective response to odors [27], odor awareness/reactivity [28], and the importance and application of olfaction. These variabilities could conceivably affect emotions, physiology and behaviors. Assessment of individual differences is critical to provide a better understanding of odor processing and olfactory related behaviors. With the rise of psychophysical and neuroimaging research in olfaction [29], psychometric tools (e.g. questionnaires and scales) appear to survive as a useful, complementary technique, especially for the qualification and interpretation of olfactory related perceptual responses. Along the way, questionnaires or scales that measure different aspects of olfaction have been developed, focusing on the importance of smell, the application of smells in daily life, or the relationship between olfaction and other psychological processes.

The aim of the current review is to provide a synthesis of the existing olfactory scales and questionnaires, to summarize their psychometric properties and correlates, and to evaluate the scales in light of other self-report measures for the assessment of 1) affective or emotional response to odor; 2) olfactory awareness and importance; 3) olfactory dysfunction; 4) olfactory imagery. Further, the advantages and disadvantages of these scales are discussed, aiming to provide researchers and clinicians with resources regarding self-report measures available of olfaction and to facilitate selection of the optimal measure for a particular clinical or research application.

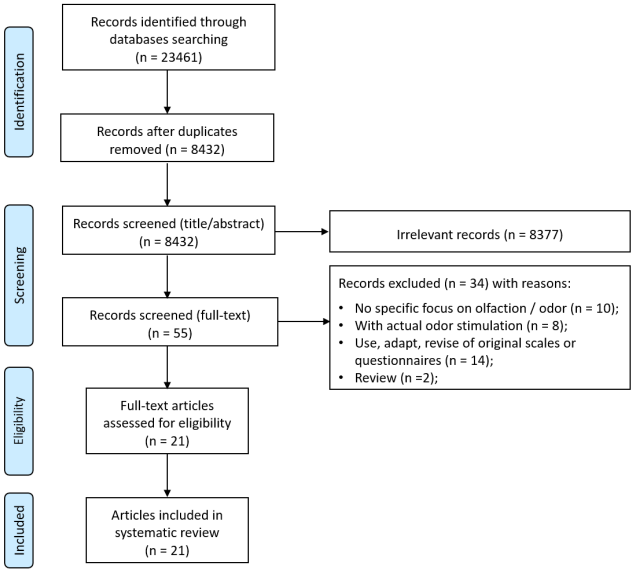

Figure 1. PRISMA flow diagram of the study screening and selection process.

Materials and methods

Article search

The initial electronic search was conducted by an author of this article (TS). Three online databases were selected: PubMed, Web of Science and PsycINFO. The following search strategy was used: (olfactory OR olfaction OR smell OR odor OR odour) AND (questionnaire OR scale OR inventory OR test OR score OR measure). Within the database no data filter was applied but the search was limited to human species and English language.

A total of 23461 records were generated. Records from different database were exported to EndNoteTM X9. After removal of duplicates, 8423 records were screened based on title, abstract, and key words. 8377 records identified as irrelevant to the review were excluded (e.g. definition of scale was inconsistent with this article, tests with actual odors, etc.). The 55 remaining articles underwent further independent full-text screening by the 2 authors of this review (TS and PH). Articles were considered relevant if both authors rated them accordingly based on the following inclusion criteria: no actual odor stimuli, describing the original development of a measurement tool, with specific focus on olfaction/smell related response or behavior. Finally, twenty-one articles were included for a comprehensive analysis. Figure 1 showed the process of literature search and screening. A summary of the questionnaires included in this review is shown in Table 1.

Table 1. Summary of olfactory related psychometric measurement (questionnaires/scales).

Article	Questionnaire/Scale	Items	Reliability	Validity tested	Investigated sample size [1]	Country	Citations[2]
Questionnaire for affective and emotional experience of odor							
Wrzesniewski et al. (1999)	Affective Impact of Odor scale (AIO)	8	αTotal=0.73-0.75	Significant correlations with odor memory, attention and association	452	USA	40
Liuzza et al. (2017)	Body Odor Disgust Scale (BODS)	12	αTotal=0.94	Significant correlation with other disgust scale, factor related to pathogen avoidance	269	Sweden	10
Szarek et al. (1997)	Chemical Odor Intolerance Index (CII)	5	αTotal=0.80-0.92	Low but significant correlation to measures of psychological distress	1964	USA	48
Bailer et al. (2006)	Chemical Odor Sensitivity Scale (COSS)	11	αTotal=0.88-0.96 test-retest reliability r=0.90	Moderate to high correlation with diverse IEI feature (all p<0.001; r value between 0.53 to 0.81)	5885	Germany	31
Nordin et al. (2003)	Chemical Sensitivity Scale (CSS)	21	α=0.88 test-retest reliability r=0.87	Good discriminant between asthma/allergy and controls; Good agreement with CII (r=0.65, p<0.001);	150	Sweden	62
Nordin et al. (2004)	Chemical Sensitivity Scale for Sensory Hyperreactivity (CSS-SHR)	11	α=0.76-0.84 test-retest reliability r=0.87	Fairly good agreement (p<0.001) with the CII (r=0.739) and tolerance for olfactory substance (r=-0.718);	50	Sweden	48
Questionnaire for awareness and attitudes towards olfaction/odors							
Smeets et al. (2008)	Odor Awareness Scale (OAS)	33	Positive awareness subscale; α=0.77 Negative awareness subscale; α=0.80	N/A	523	Netherlands	34
Cupchik et al. (2005)	Odours in Everyday Life Questionnaire (OELQ)	43	N/A	N/A	136	Canada	14
Ferdenzi et al. (2008)	Children's Olfactory Behavior in Everyday Life questionnaire (COBEL)	16	αTotal=0.78	N/A	215	France	37
Croy et al. (2010)	Importance of Olfaction Questionnaire (IOQ)	20	αTotal=0.77	N/A	123	Germany	49
Martin et al. (2001)	Attitudes Towards the Sense of Smell Questionnaire (SoSQ)	36	Liking for Odour; α=0.89 Emotional Responses to Odour; α=0.87 Dispensability of the Sense of Smell; α=0.95 Uses and Efficacy of Odour; α=0.81	N/A	105	England UK	11
Burón et al. (2013)	Relational Scale of Olfaction (EROL)	11	αTotal=0.76 test-retest reliability r=0.748	Convergent validity: Correlated (p<.001) to AIO (r=.534) and OAS (r=.625) scores;	100	Spain	7

Article	Questionnaire/Scale	Items	Reliability	Validity tested	Investigated sample size [1]	Country	Citations[2]
Okamoto et al (2016)	Child odor in parenting scale (COPs)	44	αHead=0.75, αForehand=0.96 αMouth=0.77, αNeck=0.79 αHands =0.81, αBottom=0.84	Significant correlations with SAOQ, OELQ and OAS	888	Japan	8
Questionnaire for olfactory (dys)function assessment							
Frasnelli et al. (2004)	Questionnaire of Olfactory Disorders (QOD)	52	"Negative" statements subscale α=0.93, "Positive" statements subscale α=0.54 test-retest reliability between 0.71-0.78	Significantly correlated with BDI and MI (p<0.05);	205 olfactory loss patients	Germany	124
Nordin et al. (2003)	A Scandinavian Adaptation of the Multi-Clinic Smell and Taste Questionnaire (MCSTQ-Sc)	43	N/A	N/A	50	Sweden	39
Pusswald et al. (2012)	Assessment of self-reported olfactory functioning and olfaction-related quality of life (ASOF)	12	Self-reported capability of perceiving specific odors (SRP) scale; α=0 .87 Olfactory-related quality of life (ORQ) scale; α=0 .91	Discriminant validity (p<0.001) between patients (N=35) and healthy control (N=313); Low convergent validity (correlation to Sniffin Sticks identification)	313	Austria	39
Zou et al. (2019)	Self-Reported Mini Olfactory Questionnaire (Self-MOQ)	5	αTotal=0.84	Sniffin' Sticks score (r = −.597, p<.001).	285 olfactory loss patients	Germany	1
Vernetti et al. (2012)	Hyposmia rating scale (HRS)	6	αTotal=0.89	Sniffin' Sticks score (r=.65 p < .001); Healthy control (N = 25); PD patients (N=72)		Argentina	19
Takebayashi et al. (2011)	Self-administered odor questionnaire (SAOQ)	20	N/A	Correlated (r=-.578; p<0.001) with T&T recognition threshold N = 571	571	Japan	16
Questionnaire for olfactory imagery							
Gilbert et al. (1998)	Vividness of Olfactory Imagery Questionnaire (VOIQ)	16	Split-half reliability r=.858	N/A	122	USA	40
Andrade et al. (2014)	Plymouth Sensory Imagery Questionnaire (Psi-Q)	35	αTotal=0.96 Test-retest reliability total r=.71 Olfactory subscale N/A	N/A	419	UK	28

[1] Sample size used for original validation of the questionnaire / scale; [2] Total citations searched from web of science until June 2020. Abbreviations: MI: mood inventory; BDI: Beck's Depression Inventory; α: Cronbach's alpha; IEI: idiopathic environmental intolerance; N/A: not available .

Results

Affective (valence) and emotional impact of odor

One of the most important dimensions for odor perception is the affective response [7, 30]. Smells perceived as pleasant or unpleasant often serve as potent and direct stimuli to evoke affective states [31, 32]. The Affective Impact of Odor scale (AIO) was developed to investigate the impact of good or bad smells in determining liking for new food, new places, new cosmetic health products and new persons [33]. The AIO score is calculated by taking the mean of 8 items, with higher scores indicating more impact of odors on liking for the aforementioned topics. The AIO score is correlated with odor-mediated memory, odor attention and odor affect via associations [33], but not related to odor recognition [34]. Strengths of the AIO are its brevity and its good reliability among the US and Belgian samples (Cronbach's α of 0.73 and 0.75, respectively). Another advantage is that the AIO score was shown to be strongly correlated with reactions to odors in an evaluative conditioning experiment, supporting its good convergent validity. Similarly, the Attitudes Towards the Sense of Smell Questionnaire (SoSQ) not only measures the affective impact of odor, but also covers the relative importance and the application of olfaction [35]. This measure has the advantage of good reliability for the aggregated items reflecting different aspects attitude towards odor (Cronbach's $\alpha > 0.8$ for all). The Odor Awareness Scale (OAS) elaborates the dimensions of awareness, namely the hedonic values toward odors, and evaluates the effects of odors on attention, emotion, memory, product purchase, and the sensitivity and importance of odors [36]. The OAS score is positively associated with odor memory [38]. Further, the OAS is correlated with actual olfactory function, both in the introductory study and later ones [28, 39]. OAS accounts for some of the attitudes concerning the value of odors in romantic interest, such as mate selection [40]. Current and prior olfactory related behaviors were associated with individual OAS scores [39]. Importantly, the OAS score is related to the degree and diversity [41] of odor exposure [42]. One advantage of the OAS is the wide coverage of situations with odor, such as eating and drinking, civilization, nature and human. Another advantage is that the OAS has been translated into Italian and Spanish [28, 37]. One possible disadvantage is the relatively big number of items which could bring burdensome to respondents.

It has been argued that both reduced olfactory performance (anosmia/hyposmia) as well as hyperosmia are associated with altered emotional processing. Self-ratings of odor sensitivity did not correlate with olfactory abilities, but did correlate with "odor annoyance" and the affective importance of odors as measured by the AIO scale [43, 44]. The chemical odor intolerance index (CII) is a well-validated assessment that requires people to self-report the frequency (almost never, rarely, sometimes, often, almost always) of feeling ill from the odors of five substances (pesticide, paint, perfume, car exhaust and new carpeting), and has promise as a quick and easy screening measure of chemical odor intolerance across a wide range of subjects (younger and older adults, patients with multiple chemical sensitivity condition) [45]. The Chemical Odor Sensitivity Scale (COSS) [46] assesses the strong physical responses to odor of common environmental chemicals, providing a useful research tool for assessing chemical sensitivity and promising a brief screening tool for idiopathic environmental intolerance. The Chemical Sensitivity Scale (CSS) [47] includes questions about the negative affective reactions and behavioral disruptions that individuals experience from environmental exposure to odors or pungent chemical substance. The relatively larger number of items referred to affective reactions (12 out of 22 items) suggests the favor of this facet. In addition, there is a short-version of the CSS, called the Chemical Sensitivity Scale for Sensory Hyper-reactivity (CSS-SHR). This scale has been developed for patients with sensory hyper-reactivity [48]. A strength of both the CSS and the COSS is their good test-retest reliability (r=0.87 for CSS and r=0.90 for COSS). A unique strength of the CSS is that it has been modified and tested in patients with sensory hyper-reactivity, and with normative data available [49]. One unique strength of the COSS is that the test is quite stable across time. However, the COSS has limits when attempting to predict olfactory related affective and behavioral consequences for the individuals.

Some body odors are considered to elicit disgust, which is a core emotion that evolved as a defense mechanism, for example to protect the body from potentially harmful substances and diseases [50, 51]. The Body Odor Disgust Scale (BODS) assesses the trait disgust sensitivity to body odors of sweat, feet, breath, genitals, urine, gas, and feces [52]. The scale items were set up as hypothetic scenarios in which participants had to imagine themselves detecting each of these body-generated odors sourced either from themselves or from other people. Participants had to rate to what extent each scenario elicits disgust on a Likert-type scale ranging from 1 ("not disgusting at all") to 5 ("extremely disgusting"). The BODS emphasizes the role of olfaction or body odor in activating behavioral immune system which related to pathogen avoidance [53]. One strength of this measure is the good internal consistency (Cronbach's $\alpha > 0.90$) and its brevity (12 items). Besides, the BODS presented positive correlations with chemical sensitivity scale (CSS) score, olfactory importance score and self-rated olfactory ability [52], supporting its validity. A possible limitation is that the BODS has not been investigated for cross-cultural validity.

Awareness and attitude towards olfaction

The subjective attitude towards the importance of odors or the olfactory function can be assessed with questionnaires such as the "Odor Awareness Scale" (OAS) [36] or the "Importance of Olfaction Questionnaire" (IOQ) [54]. These scales allow to estimate how much people pay attention to chemosensory stimuli in

their environments. The three subscales of IOQ evaluate the emotions, memories and evaluations associated with odors (Association-scale), the degree of application of smells in daily life (Application-scale), and the importance of smells in decision making (Consequence-scale). The olfactory importance increase with age and was generally higher for females compared to males [55, 56]. Varied levels of the general attitude as well as the subscale dimensions have been shown in population from different regions [55]. However, using selected items from the OAS, there is research demonstrating that the variability in odor awareness is largely due to gender, age and education, but less due to country [57]. One strength of the IOQ is the measure of different aspects of attitudes towards odors or olfaction, and inclusion of the aggravation scale to identify the overestimation of olfactory significance among clinical populations (e.g. patients with olfactory loss). For example, the reduced IOQ score among subjects with impaired olfactory function serves as an adaptive coping strategy, while high aggravate symptom among some smell-disordered people may indicate their insufficient coping [58].

The Relational Scale of Olfaction (EROL) evaluates the influence of odors on mood, behavior and cognition. With only 11 items, the EROL displayed good psychometric properties by showing an adequate level of test-retest reliability and the acceptable to good convergent validity [59] (Table 1). The Odours in Everyday Life Questionnaire (OELQ) was developed inquiring about the ecological, sexual, social, emotional and memory-related role of odors in everyday life, especially bodily odors [60]. However, the OELQ contains several items that are not directly related to odor awareness (e.g., item 22: Do you shave your armpits?).

The Children's Olfactory Behavior in Everyday Life questionnaire (COBEL) used food, social, and environmental odors to assess children's attention and use of odors [61]. One unique feature of the COBEL is that it is completed in the form of an interview. Besides, it is necessary to control the influence of some factors during the process of interviewing, such as language fluency of the interviewer, and guide the children to answer [41, 62]. The gender differences revealed by the COBEL had indicated that the stronger odor-orientation of human females is established in childhood [61].

The Child Odor in Parenting scale (COPs) assesses the parents' awareness and experiences of odor from different body parts (head, forehead, hand, mouth, neck and bottom) of their children in daily child care [63]. Factor modeling indicated that parental experiences with child odors can be classified into a hygiene care factor (instrumental factor; e.g., perception of the odor evokes the thought of cleaning out the odor source) and an affectionate care factor (affective factor; e.g., perception of the odor evokes sensations of love and reward). Using a group of 888 subjects, the COPs was found to have adequate content validity, concurrent validity, and reliability. Further, the concurrent validity of the COPs was measured by multiple validated olfactory scales (SAOQ, OELQ and OAS). One possible weakness for the COPs is that it penetrates frequent odor experiences, while the unique and infrequent child odor experiences (e.g. odor of sickness) were not included.

The above scales have directly or indirectly measured those aspects (attitude, memory, emotion and applications). Noted that many of the aforementioned scales have been used for clinical populations with psychiatric disorders, such as patients with panic disorder (64), or Autism Spectrum Disorder [65].

Olfactory dysfunction

The assessment of olfactory performance is a routine test in specialized clinics for olfaction. The most widely used olfactory tests are the "Sniffin' Sticks" battery [66, 67] and the University of Pennsylvania Smell Identification test [68]. The accuracy of self-reported olfactory performance is limited, but the accuracy is higher among patients with olfactory dysfunction compared to normosmic subjects [69].

The decreased quality of life (QoL) serves as an indicator for olfactory dysfunction [18]. A majority of questionnaires ask patients the consequences of olfactory dysfunction and its impact on their daily life, in order to gauge this dimension of olfactory dysfunction. As one of the most widely used questionnaires, the Questionnaire of Olfactory Disorders (QOD) determines the impact of olfactory dysfunction on daily life [70]. The QOD consists of 52 statements, which can be divided into 3 domains: 39 negative statements (degree of suffering; NS), 5 positive statements (positive effects and coping strategies) and 8 socially desired statements ("lie scale"). The QOD-NS asks the consequence of olfactory dysfunction on daily life activies, and has been used for olfactory-loss patients due to traumatic brain injury [71] or chronic rhino sinusitis (CRS) [72]. Among a group of CRS patients, the worse QOD-NS scores were shown to correlate with lower Sniffin' Sticks TDI score, and also the presence of depression [73]. The minimal clinical important difference (MCID) was developed for the QOD-NS among 128 CRS patients after endoscopic sinus surgery, with an averaged score of 5.2 (with a distribution-based range between 2.6 and 8.6 points) [74]. The QOD-NS measures four distinct factors which have differential impact on varying aspects of QoL [75]. A short-version using less than half of the questions in the QOD-NS has been validated and proved for the usefulness in clinical settings [76]. More recently, the Self-Reported Mini Olfactory Questionnaire (Self-MOQ) was developed for quantitative assessment of olfactory dysfunction [77]. With only 5 items, this assessment targets mainly the complaints about olfactory problems in daily life. Further, the Self-MOQ is an effective measure with good sensitivity and specificity for discriminating between normosmia and hyposmia (cut-off score 3.5) or anosmia (cut-off score 4.5) [77]. A strength of both the OQD and the self-MOQ is that they have good validity had included larger samples for validation. A significant advantage

of the OQD is that it has been widely referred in other research and has multi-language versions available including English [78], Mandarin [79], Korean [80], and Iranian [81]. The strength of the Self-MOQ is that, compared to the OQD, it is much shorter and less burdensome to patients. One possible weakness is the lack of test-retest reliablility information.

The Multi-Clinic Smell and Taste Questionnaire (MCSTQ) was initially developed in the US (also adapted for Scandinavia: MCSTQ-Sc) [82]. The MCSTQ-Sc explicitly assesses the self-reported odor sensitivity, distorted smell (parosmia) and phantosmia, including the presence, degree and duration of the symptoms. All questions are listed with detailed instruction for responses. Besides, it also contains questions pertaining to the consequences of olfactory dysfunction on daily life and the coping strategies. The MCSTQ had been used for special populations with altered sense of smell, such as pregnant women [83]. However, there was no information regarding the validity or reliability for MCSTQ. Similarly, the Cardiff Anomalous Perception Scale (CAPS) [84], contains a few items about the anomalous odor perceptual experience (qualitative and quantitative).

Clinically, subjective testing can be performed using a one-item question (e.g. do you have a normal olfactory function), single visual analogue scales or Likert questionnaire. However, assessment outcomes using those tools usually showed poor correlation with actual olfactory functions as measured using standard psychophysical tests [85-87]. Several questionnaires on olfactory dysfunction were developed with detailed quantification of olfactory function, including questions regarding the degree or frequency of odor perception. The Self-Administered Odor Questionnaire (SAOQ), proposed by the Japan Rhinologic Society Committee, contains 20 smell-related questions and asks patients to mark the degree of perception to each of the odor [88, 89]. Compared to the self-administered olfaction test using a single visual analogue scale (VAS), the SAOQ showed higher sensitivity, specificity and positive and negative predicted values, suggesting its superiority as olfactory test compared to VAS. The five-item self-reported capability of perceiving specific odors scale (one subscale of ASOF) assesses the frequency of odor perception (from very often to never) [90]. Similarly, the Hyposmia Rating Scale (HRS), which was initially designed for patients with Parkinson's disease, contains six scenarios in which the patients need to rate the frequency (e.g. always, sometimes, only after being made aware of, and never) of perception [91]. In comparison to the single screening question asking whether or not a patient has smell problems, the aforementioned scales are with more clinical relevance. A strength of the aforementioned SAOQ and HRS assessing olfactory functions is that they showed good correlations with T&T odor threshold and Sniffin' Sticks test scores respectively, which suggested their validity for olfactory function assessments. A weakness for the HRS is the inclusion of a small sample size for its validation, and may not have adequate power for clinically significant. Another weakness is the ceiling effect observed for the HRS which was resulted in decreased specificity. The SAOQ contains odors that are familiar to East Asian people (e.g. soy sauce and steamed rice) which may limit its usefulness among people from other regions.

Taken together, in clinical practice, patients can be interviewed or screened for olfactory dysfunction using questionnaires. As a comprehensive olfactory evaluation, it enables systematic evaluation of the patient and yet requires only limited clinical time. The questionnaire can be completed by the patient prior to the clinical visit or during the waiting time between clinical examinations. However, for clinical practices, it is clear that objective olfactory function tests are needed for proper diagnosis. Results from questionnaires are needed to put the clinical results into perspective.

Olfactory imagery

Olfactory imagery refers to the experience of odor perception without appropriate odor stimulation [92, 93]. The ability to form olfactory image is mainly reflected by the representational clarity (e.g. vividness of mental images) [94]. The Vividness of Olfactory Imagery Questionnaire (VOIQ) measures the olfactory representation ability [96]. Screening based on the scale is a simple and effective method to distinguish individuals with high or low olfactory representation abilities. The VOIQ contains 16 scenes with different odors and asks people to evaluate the vividness of the imagined odor using 5-point scale ("1 - perfectly realistic and as vivid as the actual odor" to "5 - No odor at all, you only know that you are thinking of the odor") [96]. Good olfactory imagers (scored higher on the VOIQ) rated pleasant smell as more familiar and had lower anhedonia scores compared to "bad" olfactory imagers, suggesting that individual difference in olfactory imagery vividness is associated with emotions and long-term olfactory memory [97, 98]. People with good olfactory representations are more likely to recall the pleasure of sensory perception, while those with poor olfactory representations report greater difficulty in recalling pleasant sensory experiences [99]. Besides, people with higher olfactory imagery ability show stronger interest in olfaction [100]. The ability to create olfactory images is also related to the lexical knowledge of odors, for example, the ability of naming odor. Olfactory experts, who are characterized by a very high level of lexical knowledge of odors, often report good odor imagery ability [14, 101]. The Plymouth Sensory Imagery Questionnaire (Psi-Q) provides a measure of vividness of imagery across a range of sensory modalities. For olfaction, the Psi-Q asks participants to imagine five different nonfood odors and rate their image on an 11-point scale anchored by 0 (no image at all) and 10 (as vivid as real life) [102]. One advantage of the VOIQ and Psi-Q is that they showed good reliability. Besides, the Psi-Q could provide direct comparison of imagery between olfactory and other modalities. Another

advantage of the Psi-Q is that it has been validated in Spanish [103]. One possible disadvantage of the VOIQ is that there is no information reported on the criterion validity.

Olfactory (and visual) imagery are emerged as part of craving processes since substance craving is often accompanied by vivid and frequent olfactory and taste imagery [104, 105]. Olfactory imagery can influence eating behaviors [106]. Patients with peripheral smell loss show a decreased vividness of olfactory representations [108, 109]. Olfactory mental imagery also interferes with the ability of self-rating one's own olfactory abilities, for example, people with normal (normosmia) or partially reduced (hyposmia) olfactory function maintain that they rely on their ability to imagine odors to evaluate their own olfactory performance [109], although there is conflicting evidence [108].

Recent questionnaires attempt to measure different components of imagery (visual imagery) ability in terms of the underlying sub processes such as image generation, maintenance, inspection, and transformation. However, little progress had been made so far there has been few questionnaires developed on these theory-based sub processes of the olfactory imagery [110]. Additionally, a few other questionnaires were developed targeting specific olfactory imagery related behaviors, for example, olfactory dreaming [111]. A questionnaire for olfactory dreaming examines the olfactory imagery among people with reported dreaming odors [112].

Discussion

This review summarized and evaluated the olfactory related psychometric tools (questionnaires and scales). Although most reviewed questionnaires or scales are multifaceted, they were classified into several categories according to the initial purpose of development, namely the affective responses to odors, awareness and attitudes towards olfaction, olfactory function/dysfunction related quality of life, and olfactory imagery. A close examination of the items/questions and careful consideration of the advantages and disadvantages of the measurement are necessary to determine the best suited measure for the desired purposes. Among the factors relevant to that a decision are the group to be assessed (individuals with normal olfaction or smell dysfunction), or the interest of the study (affective/emotional aspect of olfaction or QoL related issues). In some cases, modifications and validation will be necessary. The validity of reviewed questionnaires/scales is supported by evidences from experimental and longitudinal studies. First, sex difference has been one of the most noteworthy and consistent findings from several psychometric measurements. To illustrate, women compared to men paid more attention to olfactory related cues [61], showed higher interest in the sense of smell and a higher reported importance of olfaction [55, 113]. This larger interest or importance can be expected to lead to gender differences in olfaction-based decision making and behaviors [114]. In the same vein, impairment of olfactory function seems to lead to more complaints in females than in males [70, 72]. Moreover, females compared to males have significantly higher disgusting sensitivity to body odor [52].

Notwithstanding the intrinsic limitations to many of the psychometric measures, such as sample bias or answers reflecting self-perceived behavior rather than behavior itself, the values of such tools are to provide assessment of the olfactory related behaviors that are difficult to be assessed with other approaches and have had less reflection in the literature. Additionally, those questionnaires/scales can be easily distributed to large population when social distance has to be kept under certain circumstances, the COVID-19 outbreak, for instance. When initially developed, most of the tools were thought to assess individual variations of certain olfactory related behaviors that represent a trait-like individual characteristic that remains stable over time. However, little research had been conducted for their long-term stability. Future work would also benefit from inclusion of more diverse samples (in education, income, race and ethnicity aspects) and multimodal assessments, including a combination of self-report, cognitive processing, behavioral and physiological measurements of olfactory related responses. For example, it is essential to further study the basic neural and cognitive processes underpinning the self-reported scores on psychometric olfactory measurements.

Many of the reviewed questionnaires/scales had been used for clinical populations. For example, in certain people the sense of smell has a high subjective significance when it is impaired [115], while others may not even recognize their olfactory loss [24]. Odor awareness was found to be changed in disease such as Autism Spectrum Disorder [65]. When repeated measures are conducted, these tools are also useful in characterizing the clinical effect of interventions, including the MCID [74]. Given the above issues, these should not be performed in isolation. Rather, when diagnosing olfactory impairment, or assessing the effects of treatment, patient reported outcomes should be used in conjunction with more objective forms of assessment.

Conclusion

In conclusion, a range of psychometric scales or questionnaires are available tapping on inter-individual differences in olfactory awareness, olfactory affection and emotion, olfactory function/dysfunctions, and the ability to create olfactory mental images. A review of these psychometric tools could assist psychologists, biologists, clinical scientists, and neuroscientists to select olfactory scales suitable for research with different experimental purposes and specific populations. Especially for clinical practice, questionnaires seem to be a time-efficient and elegant instrument to get an impression of the subjective meaning of the olfactory deficit. Characterization of these features among patients could also help in future interventions, especially to

improve the olfactory related QoL. As an important complementary approach, such validated assessments could help to achieve a better understanding of the causal path between self-reported olfactory related responses and health effects from odors and their importance in daily life.

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Conflict of interest

None.

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