A review of the effects of valenced odors on face perception and evaluation

Elmeri Syrjänen¹, Håkan Fischer¹, Marco Tullio Liuzza^{1,2}, Torun Lindholm¹, and Jonas K. Olofsson¹

¹ Department of Psychology, Stockholm University, Stockholm, Sweden

²Department of Surgical and Medical Sciences, "Magna Graecia" University of Catanzaro, Catanzaro, Italy

How do valenced odors affect the perception and evaluation of facial expressions? We reviewed 25 studies published from 1995 to 2020 on cross-modal effects between olfaction and facial perception. The results indicate that odors may influence facial evaluations and classifications in several ways. Faces are rated as more arousing during simultaneous odor exposure, and the rated valence of faces is affected in the direction of the odor valence. For facial classification tasks, in general, valenced odors, whether pleasant or unpleasant, decrease facial emotion classification speed. The evidence for valence congruency effects was inconsistent. Few studies found that exposure to a valenced odor facilitates the processing of a similarly valenced facial expression. The results for facial evaluation were mirrored in classical conditioning studies. Faces conditioned with valenced odors were rated in the direction of the odor valence. However, the evidence was inconsistent in facial classification tasks in this literature. Although the research shows some clear patterns, other effects are mixed. Our future research recommendations include greater consideration of individual differences in sensation and cognition, individual differences (e.g., differences in odor sensitivity related to age, gender, or culture), establishing standardized experimental assessments and stimuli, larger study samples, and embracing open research practices.

Introduction

Inferring other peoples' emotional states from their facial expressions is an essential social ability. Historically, facial perception has been studied in isolation; however, social cues are

1 often ambiguous and rely heavily on contextual information for correct interpretation (Aviezer,
2 Ensenberg, & Hassin, 2017). How we interpret facial expressions may vary by previous
3 experiences, cultural background, and context (Barrett, Adolphs, Marsella, Martinez, & Pollak,
4 2019). In line with this reasoning, several recent reviews have considered the effects of auditory
5 context (Gerdes, Wieser, & Alpers, 2014), visual cue context, background scene, body posture,
6 situation, culture, and individual differences (Aviezer et al., 2017; Wieser & Brosch, 2012).
7 However, the contextual effects of odors on facial perception have received less interest.
8 Human olfactory abilities are capable of detecting environmental odors even at minute
9 concentrations (McGann, 2017), but olfactory perception needs visual confirmation to establish
10 its identity or social relevance (Olofsson & Gottfried, 2015). This research review aims to
11 integrate the emerging insights from how odors are perceptually integrated with emotionally
12 expressive face stimuli.

13
14 Olfaction provides an interesting vantage point for studying cross-sensory integration of
15 emotional cues. Olfaction has been described as an inherently emotionally evocative sense,
16 presumably because of its close integration with the limbic system (Soudry, Lemogne,
17 Malinvaud, Consoli, & Bonfils, 2011). Olfaction is involved in detecting and identifying health
18 hazards (e.g., fire, bad food) and food and nutrition (de Vries et al., 2020; Stevenson, 2010).
19 This link between olfaction and survival might explain the emotional nature of the olfactory
20 system. For example, valenced odors can elicit basic emotions, most notably happiness and
21 disgust (Alaoui-Ismaïli, Robin, Rada, Dittmar, & Vernet-Maury, 1997; Croy, Olgun, &
22 Joraschky, 2011; Glass, Lingg, & Heuberger, 2014). Thus, odors have profound emotional and
23 motivational effects on human behavior.

24
25 Due to the close link between odors and emotions, odors might affect the processing of social
26 cues. There is a broad agreement that olfaction's main hedonic dimensions are valence and
27 arousal (Anderson et al., 2003; Bensafi, 2002). Valenced odors might, perhaps unsurprisingly,
28 affect mood states such that pleasant odors have a positive effect. In contrast, unpleasant odors
29 have a negative effect on mood (Herz, 2009), and odors may also be experienced as energizing,
30 sensual, or disgusting (Ferdenzi et al., 2011). In general, the arousing properties of odors may
31 facilitate the overall processing of stimuli. Corroborating this notion, (Millot, Brand, & Morand,
32 2002) found faster reaction times (RTs) to simple visual and auditory cues in both unpleasant
33 and pleasant odor contexts compared to a no-odor context. Apart from the general arousing
34 properties of odors, there is evidence of odor-visual integration from research on object

1 congruency. Smelling an orange can increase visual attention towards oranges (Seo, Roidl,
2 Muller, & Negoias, 2010). Behavioral studies also show that congruent cues from olfactory and
3 visual objects are processed in parallel in the early stages of stimulus processing, but they are
4 combined at later stages to benefit behavioral decisions (Amsellem, Hochenberger, & Ohla,
5 2018). Thus, there are several ways by which odors might influence facial perception, including
6 arousal and valence effects, as well as their interactions with facial expressions that are
7 congruent or incongruent with the emotion elicited by the odor.

8
9 In ecological settings, perception is often multisensory. Previous research has shown that when
10 we use congruent cues from multiple modalities, our ability to recognize objects becomes faster
11 and more accurate. For example, in a noisy environment, seeing a speaker's lips will improve
12 the ability to hear the verbal content (Ross, Saint-Amour, Leavitt, Javitt, & Foxe, 2007). Odors
13 can, in a similar manner as hearing, influence visual perception. Most research on the influence
14 of odors on perception has focused on matching congruent vs. incongruent object cues (e.g.,
15 the smell and picture of an orange), presumably because such matching corresponds to the
16 processing demands of widely used odor identification tests (Doty, Smith, McKeown, & Raj,
17 1994; Hummel, Sekinger, Wolf, Pauli, & Kobal, 1997; Olofsson & Gottfried, 2015). Here we
18 focus instead on the relation between odor and perception of facial expressions. Effectively
19 integrating odor and face cues might help evaluate the source and potential health hazards
20 associated with the odor. However, the emotional properties of odors might also lead to biased
21 evaluations of face stimuli. The current review thus focuses on how odors affect the perception
22 of faces.

23
24 The basic emotion theory (Ekman, Sorenson, & Friesen, 1969) posits six universal basic
25 emotions (happiness, fear, disgust, anger, surprise, and sadness), each associated with distinct
26 facial expressions, physiological changes, and behavioral patterns. However, many of these
27 assumptions, such as the universality (Russell, 1993), facial expressions (Barrett et al., 2019)
28 and physiological changes (Lindquist, Wager, Kober, Bliss-Moreau, & Barrett, 2012) of the
29 basic emotion theory have been questioned. As noted above, recent theoretical work has
30 emphasized the contextual effects in emotions (Barrett, 2017a). In this view, in emotion
31 perception, all available information is used to predict and correct our model of the world using
32 active inference such as past experiences, culturally appropriate displays, and contextual
33 information in our environment (Barrett, 2017b). The last 25 years have seen a steady increase
34 in research on contextual effects on facial perception. In our current review, we retain the

classification of emotional expressions provided by the basic emotion theory. However, we highlight the importance of how an olfactory context affects facial perception and associated behaviors. The behavioral measures comprise affective ratings, emotion classification accuracy, and response times (RTs) in various tasks.

Method

We performed searches in Google Scholar, PsycINFO, PubMed, and Web of Science for keywords: (face, odor, smell, olfaction & cross-modal), as well as in our databases of articles, with the last search conducted on September 1, 2020. Articles matching our criteria were also manually searched in the reference lists of all included articles. We did not include studies attempting to study human pheromones or chemosignals; as this research is based on assumptions of unique properties of certain chemosensory stimuli, these reports fell outside of our review's scope to integrate research findings across different stimuli and experimental settings whenever possible. We included articles that fulfilled the following inclusion criteria.

1. Peer-reviewed empirical studies available in English
2. Healthy adult participants
3. Reported behavioral effects of odors on the perception of faces

Results

In total, we found 25 articles matching the inclusion criteria; these articles were published from 1995 until September 2020 and are presented with summaries in Table 1. The table comprises the studies listed in chronological order, an overall description of the design, stimuli, participants, and main findings.

An overview of the included studies allows for some general observations regarding the most commonly used methods and stimuli. The methods can be roughly divided into three experimental paradigms. First, facial emotion classification tests where RT and accuracy levels were measured. Second, subjective evaluations (i.e., ratings of facial valence and arousal) during exposure to various odors. Third, classical conditioning studies where neutral faces were associated with valenced odors; these studies used both emotion classification tasks and facial evaluations as outcome measures. Several studies included electrophysiological measures or

functional magnetic resonance imaging (fMRI); however, here, we focus on behavioral effects. Odor stimuli were typically either clearly pleasant (vanillin and floral-based, such as jasmine) or unpleasant (valeric acid, hydrosulfide, methyl mercaptan, and fish). A majority of the included studies also used clean air as a no-odor control condition; however, few studies used emotionally neutral odors as a control. Common facial expressions used in the reviewed studies were happy, neutral (most prevalent in associative learning studies), disgusted, fearful/anxious, and angry expressions.

Table 1: Description and main results of behavioral studies of face perception during odor exposure, studies listed chronologically.

Study (year)	Design	Odor delivery Event/Blocked (E/B)	Stimuli Odor/Face (O/F)	N Female/male (F/M)	Main findings
Todrank, Byrnes, et al. (1995)	Liking of neu faces paired with ple, neu, or unple odors. Exp 1, 2, 4 people-related odors. Exp 3, object-related odors.	E	O: Ple, neu, unple F: Neu	Exp 1: 20 (15 F) Exp 2: 15 (11 F) Exp 3: 14 (9 F) Exp 4: 23 (16 F)	Faces paired with people-related odors were liked in the direction of odor valence in Exp 1,2 & 4. This effect was not evident in Exp 3, where object-related odors were used.
Cann & Ross (1989)	Attractiveness of attractive and unattractive female faces during exposure to ple, no-odor, or unple odors.	B	O: Ple, no-odor, unple F: Neu	63 M	Odors did not affect attractiveness ratings
Hermann, Ziegler, Birbaumer, and Flor (2000)	Val and arousal ratings (SAM-scale) of neu faces conditioned by startle sounds during exposure to ple (n=15) or unple odor (n=15).	E	O: Ple, unple F: Neu	30 M	Faces paired with a startle sound during unple odor exposure were rated as more arousing and neg than other conditions. Faces paired with a startle sound during a ple odor exposure were rated as more arousing but not more pos.
Bensafi, Pierson, et al. (2002)	Neutral faces classified as ple or unple during exposure to ple odor or no-odor.	E	O: Ple, no-odor F: Neu	15 F	Ple odor did not affect face classification.
Gottfried, O'Doherty, and Dolan (2002)	Neu faces paired with ple, no-odor, or unple odor. RTs obtained in face gender classification task.	E	O: Ple, no-odor, unple F: Neu	17 (10 F)	Slower RTs for faces conditioned to ple and unple odors in the first block, no-effect in the second and third block.

Leppanen and Hietanen (2003)	Exp 1. Face emotion classification task (happy or disgusted) during ple or unple odor exposure. Exp 2. Similar to 1 but with a between-groups design, added neu faces, and no-odor controls.	B	Exp 1. O: Ple, unple F: Happy, Disgusted Exp 2. O: Ple, no-odor, unple F: Happy, neu, disgusted	Exp 1: 20 (15 F) Exp 2: 45 (40 F)	Exp 1. Happy faces recognized faster in ple odor context; effect was absent in unple odor condition, where disgusted faces were recognized slightly faster. Exp 2. Happy faces recognized faster in ple odor context, slower in no-odor control, and slowest in unple odor condition.
Gottfried and Dolan (2004)	2 CS+ neutral faces paired with UCS odors, 2 faces CS- not paired with an unple odor. RTs for gender identification, faces were rated (VAS) on intensity and valence.	E	O: Unple F: Neu	18 (10 F)	Faster RTs to CS+ first half of the exp. CS+ faces were rated as more neg val compared to CS-.
Dematte, Osterbauer, and Spence (2007)	Women rated (VAS) attractiveness of male faces during exposure to ple and unple odors.	E	O: Ple, unple F: Neu (varying in attractiveness)	16 F	Faces rated as less attractive during exposure to unple odor.
Li, Moallem, Paller, and Gottfried (2007)	Likeability of neu faces rated (VAS) after exposure to sub-threshold ple, neu, no-odor, and unple odors.	E	O: Ple, neu, no-odor, unple F: Neu	31 (18 F)	Odor-unaware subgroup (n=15) rated faces as less likable after unple than after ple odor.
Seubert, Loughhead, et al. (2010)	Emotion classification task (happy, neu, disgusted faces) in event-related design with ple, no-odor, and unple odors.	E	O: Ple, no-odor, unple F: Happy, neu, disgusted	24 (10 F)	Faster and more accurate classification of disgust in ple and unple odor condition than in neutral odor condition. Response times to happy faces increased in ple and unple odor conditions compared to neu odor.
Seubert, Kellermann, et al. (2010)	Emotion classification task (on happy, neu, and disgusted faces) in an event-related design with a ple, no-odor, and unple odors.	E	O: Ple, no-odor, unple F: Happy, neu, disgusted	44 (23 F)	Faster classification of disgust in ple and unple odor
Steinberg et al. (2012)	Face valence and arousal ratings (SAM) to CS+ (unple odor) and CS- faces	E	O: Unple, no-odor F: Neu	24 (12 F)	CS+ faces rated as more negative post conditioning, no arousal effects.
Steinberg et al. (2013)	Preference for neu faces when previously paired with ple, no-odor, or unple odors.	E	O: Ple, no-odor, unple F: Neu	23 (12 F)	Preference for face depended on associated odor (pleasant > neutral > unpleasant).

Seubert, Gregory, Chamberland, Dessirier, and Lundstrom (2014)	Classification of target faces as older or younger than a cue face. Ratings (VAS) of age and attractiveness.	E	O: Ple, unp odor mixtures controlling for intensity (linearly increasing in val from ple to unp). F: Neu (varying in attractiveness and age)	18 (12 F)	Faces were rated as more attractive and younger in ple compared to unp odor condition.
Cook et al. (2015)	Val ratings (VAS) of neu faces primed by a ple, no-odor, or an unp odor	E	O: Ple, no-odor, unp F: Neu	23 (12 F)	Ratings of faces were affected by odor priming in the direction of odor val.
Leleu, Demily, et al. (2015)	Matching faces with varying levels of emotional expressions during exposure to ple, no-odor, and unp odor.	B	O: Ple, no-odor, unp F: Happy, angry, fearful & sad (morphed with neu for emotion levels)	48 (31 F)	Congruent odors increased sensitivity for face emotion matching (e.g., happy faces in the ple odor condition) for happy, disgusted, and angry expressions. Fewer false alarms for disgusted faces in the unp odor condition when emotion labels for faces were provided. Without labels, more false alarms were provided for neg emotions in the ple odor context.
Novak et al. (2015)	Val ratings (VAS) and emotion classification of neu and fearful faces during neu or sub-threshold unp odor exposure.	E	O: Neu, unp (diluted with neu odors below detection threshold) F: Neu (morphed with fearful faces in 2% or 12%)	16 (8 F)	No effects of odors on rated val or emotion recognition accuracy
Cook et al. (2017)	Val ratings (VAS) of neutral faces during exposure to a ple, unp, or neu odor.	E	O: Ple, no-odor, unp F: Happy, disgusted	23 (13 F)	Happy faces were rated more ple during exposure to a ple odor than neu or unp odor; disgusted faces rated as less ple during exposure to unp odor compared to plea and neu odor.
Syrjänen et al. (2017)	Ratings (VAS) of facial expressions during exposure to unp, no-odor, and ple conditions. RTs and accuracy in emotion classification task of changing faces.	B	O: Ple, no-odor, unp F: Happy, neu, disgusted	21 (13 F)	Odors did not affect ratings of face valence or arousal. Faster classification of faces in unp odor condition. Classification accuracy was not affected by odors.
Damjanovic, Wilkinson, and Lloyd (2018)	Detection of facial emotion in a visual search task during odor exposure (ple, no-odor, or unp odors).	B	O: Ple, no-odor, unp F: Happy, neu, angry	54 (43 F)	Faster detection of happy faces in neu and unp odor conditions. Similar effect for ple odor early in the experiment, but effect decreased over time. In contrast, unp odor made detection of happy faces faster later in the experiment.

Cook et al. (2018)	Valence ratings of neutral faces during, or one second after exposure to a ple, no-odor, or unp odor.	E	O: Ple, no-odor, unp F: Neu	28 (18 F)	Faces rated less ple when primed with unp odor; effect largest when odor and faces were presented concurrently.
Syrjänen et al. (2018)	Val and arousal ratings (SAM) of facial expressions during exposure to unp, ple, and no-odor	B	O: Ple, no-odor, unp F: Happy, neu, disgusted	58 (33 female)	Faces rated more neg during unp odor exposure. Happy faces were rated as less arousing in unp than ple odor condition.
Syrjänen et al. (2019)	Val and arousal ratings (SAM) of facial expressions during exposure to unp, ple, and no-odor	B	O: Ple, no-odor, unp F: Happy, neu, disgusted	40 (22 F)	More pos ratings in the ple odor and more neg ratings in the unp odor exposure. Higher arousal ratings during odor exposure vs. no-odor.
Li et al. (2020)	Emotion classification task on happy, neu, and fearful faces during exposure to ple, neu, or unp odors.	B	O: Ple, no-odor, unp F: Happy, neu, fearful	54 (28 F)	Higher accuracy during unp odor exposure. Faster classification in unp odor condition. Effect was pronounced for fearful faces.
Stankovic et al. (2020)	Binary face classification task (emotion vs. neutral) with stimuli in right or left visual field. Breathing through either left or right nostril during unp odor exposure.	B	O: Unp F: Neu, happy, surprised, fearful, angry, disgusted, sad	60 F	Better classification of emotional faces in the right than the left visual field during unp odor exposure. Participants faster at recognizing faces in left visual field during exposure to odors in right nostril.

1

2 Unp = unpleasant; ple = pleasant; neu = neutral; pos = positive/positively; neg =
3 negative/negatively; exp = experiment; val = valence/valenced.

4

5 Discussion

6 The overall pattern emerging from the reviewed studies suggests that valenced odors indeed
7 affect face evaluations. The most consistent finding is that valenced odors affect evaluations in
8 general (e.g., all faces are perceived as more unpleasant in an unpleasant odor condition). This
9 indicates that a valenced odor might change the participants' emotional state, which biases their
10 evaluation of faces, or that when making valence evaluations of a face, participants misattribute
11 the source of the being evaluated. A few studies show odor-face congruency effects on
12 evaluations (i.e., that the combination of an odor eliciting an emotion affects the processing of
13 faces expressing specifically that emotion). In emotion classification tasks, a few of the studies

found evidence for odor and facial expression integration. However, the majority of the findings indicated enhanced response latencies in odor conditions relative to no-odor control conditions. The experimental paradigms used can be divided into two categories; first, effects of valenced odors, and second, classical conditioning with valenced odors, such that the valenced odor effect appears via a previously established association to the face stimulus. The results are reviewed in more detail below.

Odor effects on the processing of face stimuli

In this review, nine studies used response times as a measure to investigate the effects of valenced odors on emotion recognition. (Leppanen & Hietanen, 2003) were the first to show that pleasant odors facilitated the classification accuracy of happy faces. In contrast, the speed of classifying disgusted faces was not affected by either pleasant or unpleasant odors. In the same study, a second experiment confirmed the effect of pleasant odors on happy faces. Although several studies have used similar methods as Leppanen and Hietanen (2003), this study's odor-face congruency effects have not yet been replicated. Instead, in a similar experimental design, Li, Jia, and Wang (2020) found that facial expressions (happy, neutral, and fearful) were overall recognized faster in an unpleasant food odor context. This effect was most pronounced for fearful faces. The effect was not present for happy faces in the pleasant odor condition. In two separate studies by Seubert and colleagues, the results showed only an overall effect of odor presence on improving face classification (Seubert, Kellermann, et al., 2010; Seubert, Loughhead, et al., 2010). In one of these studies, participants were more accurate and faster in recognizing disgusted expressions in both the pleasant and unpleasant odor conditions and slower at recognizing happy faces than in the neutral condition (Seubert, Kellermann, et al., 2010). In the second study, the results were similar, but this time only present for disgusted faces (Seubert, Loughhead, et al., 2010). Hence, these results are difficult to consolidate. One reason for the heterogeneity of results might be that performance is already close to the ceiling level in a simple task such as emotion classification. If odor effects are generally relatively small, there is not much room for improvement. The results of (Leleu et al., 2015) hints at this possibility. In this study, emotional expressions were morphed with neutral faces to show various levels of emotional intensity. The results demonstrated that facial expressions morphed with neutral faces were recognized at lower levels in congruent odor conditions (e.g., happy faces in the pleasant odor condition), for happy, disgusted, and angry facial expressions (Leleu et al., 2015). However, the results in a recent study by (Syrjänen, Liuzza, Fischer, & Olofsson, 2017) showed that the recognition of dynamically morphing

1 happy or disgusted faces was not affected by congruent odors. In the latter study, exploratory
2 results indicated that happy and disgusted expressions were recognized faster during exposure
3 to an unpleasant odor. Some studies have also presented stimuli in the left and right visual
4 fields. In (Stankovic, Nesic, & Milic, 2020), participants performed an emotion classification
5 task on neutral or happy, surprised, fearful, angry, disgusted, and sad facial expressions.
6 Pictures of faces were presented in the left or right visual fields while participants were exposed
7 to an unpleasant odor in the left or right nostril. Participants were faster at recognizing faces
8 overall in the left visual field (right hemisphere) during exposure to the odor in the right nostril
9 (right hemisphere), indicating a cross-modal confluence in the right hemisphere resulted in a
10 processing speed advantage; however, the study had no neutral control condition, so it is
11 possible that the arousing effect of the odor, irrespective of its valence, improved processing of
12 faces in the stimulated hemisphere (Stankovic et al., 2020). The right-hemisphere effect is
13 consistent with results from our team that the face-sensitive N170 ERP component is more
14 prominent in the right hemisphere; furthermore, our study showed that the responsivity of the
15 N170 to disgusted faces is enhanced by an unpleasant odor (Syrjänen et al., 2018). Another
16 recent study investigated whether odors might direct attention toward odor-congruent happy
17 and disgusted facial expressions in a dot-probe task (Syrjänen, Fischer, & Olofsson, 2019).
18 However, this study's results gave no evidence that attention was automatically directed
19 towards odor-congruent facial expressions. However, the results instead indicated that probes
20 in the unpleasant odor condition were uniquely detected more rapidly over repeated trials within
21 a block, raising the possibility that visual processing benefits of malodor exposure might
22 accumulate over time. Similar time-on-task effects were found by (Damjanovic, Wilkinson, &
23 Lloyd, 2018) in a visual search task. The authors found that happy faces were recognized faster
24 initially in a pleasant and an unpleasant odor context; however, this effect was reversed toward
25 the end of the task.

26
27 While there is some evidence to suggest valenced odors might improve visual processing of
28 emotionally congruent facial expressions, especially the combination of unpleasant odor and
29 disgusted or fearful faces, the evidence is mixed. Increasing task difficulty employing brief face
30 duration times, subtle or morphed expressions, etc., might be needed to achieve consistent
31 effects of background odors. There are also some indications that odor effects develop as a
32 function of exposure time during the experiment. Not accounting for such effects might explain
33 some of the mixed findings.

Odor effects on evaluations of faces

Ten studies assessed how valenced odors affect the subjective properties of faces. Two of these studies showed that neutral faces were rated as more unpleasant in the context of an unpleasant odor (Cook et al., 2015; Cook et al., 2018) and more pleasant during a pleasant odor context (Cook et al., 2015). However, one study did not find any effect of pleasant odors on classifying neutral faces as either pleasant or unpleasant, which might indicate that binary classifications of faces are less sensitive than ratings to the presumably subtle influence of odors (Bensafi, Pierson, et al., 2002). Several studies have shown that faces, regardless of expression, are rated as more arousing and that the face valence is affected in the direction of the odor valence (Syrjänen et al., 2019; Syrjänen et al., 2018). However, results are not entirely consistent in this literature. Using Bayesian statistics, Syrjänen et al. (2017) found evidence against odor effects in face evaluations.

Ratings are also used to study valence congruency effects. One study showed congruency effects between facial expressions and odor valence; faces displaying happiness were rated as more pleasant during exposure to a pleasant odor, and disgusted faces were rated as more unpleasant during exposure to unpleasant odor (Cook et al., 2017). Odors may also affect facial attractiveness, a construct closely related to pleasantness; in one study, faces were rated as younger and more attractive-looking in a pleasant odor context (Seubert, Gregory, Chamberland, Dessirier, & Lundstrom, 2014). In a similar vein, Dematte, Osterbauer, and Spence (2007) found that faces were rated as less attractive in the presence of an unpleasant odor. However, Cann and Ross (1989) found no effects of pleasant and unpleasant odors on attractiveness evaluations in a blocked design. Finally, one study indicated that such facial evaluations were affected by odor exposure at a subthreshold level. Here Li, Moallem, Paller, and Gottfried (2007) found that only participants unaware of the presence of unpleasant odor were influenced to rate neutral faces as less likable. However, the evidence reviewed above suggests that also readily perceived odors may have similar influences on face evaluations.

Olfactory conditioning: learned odor-face associations

In conditioning paradigms, associations between stimuli are created by simultaneous presentations. Here, we focus on olfactory conditioning studies that use face and odor stimuli. In studies on this topic, an unpleasant odor (unconditioned stimuli, UCS) is usually associated with a face (CS+) by presenting these concurrently; faces that are not associated with the UCS (CS-) are used as a control. Some studies have used odors as a contextual cue and instead used

1 startle sounds (sudden loud noises) as UCS (Hermann, Ziegler, Birbaumer, & Flor, 2000).
 2 These designs allow studying how learned cross-modal associations shape the processing of
 3 face stimuli; faces associated with unpleasant odors as CS+ may be processed differently from
 4 the CS- associated faces. Two studies have shown response-time effects in a gender
 5 classification task, but results are inconsistent; CS+ faces associated with an unpleasant
 6 olfactory UCS were initially faster at the beginning of the task (Gottfried & Dolan, 2004).
 7 However, in another similar study (Gottfried, O'Doherty, & Dolan, 2002), results showed
 8 slowed responses to the CS+ faces conditioned with either pleasant or unpleasant UCS odors.
 9 More research with high-powered samples is needed to establish how valenced odor
 10 conditioning might modulate face classifications.

11
 12 Several conditioning studies have shown similar results as when odors and faces are presented
 13 concurrently, faces previously conditioned by an unpleasant odor are evaluated more negatively
 14 (Hermann et al., 2000; Steinberg et al., 2013; Steinberg et al., 2012). Steinberg et al. (2013)
 15 found that faces conditioned with pleasant odors were preferred over faces paired with clean
 16 air and an unpleasant odor. In four experiments, Todrank, Byrnes, Wrzesniewski, and Rozin
 17 (1995) found that neutral faces associated with pleasant and unpleasant odors were liked and
 18 disliked, respectively. However, this effect was only consistent with odors that were people
 19 related (e.g., soap or sweat like odors), but not for object-related odors such as woody cedar-
 20 like odors. One study showed that faces were rated as more arousing if they were paired with
 21 either pleasant or unpleasant odors (Hermann et al., 2000). Thus, similarly to contextual odors,
 22 odor conditioning seems to have robust effects on facial evaluation, with odors biasing the
 23 evaluation of faces in the odor valence direction. This capacity is highlighted in a study by
 24 (Steinberg et al., 2012). The authors showed that in a stimulus set of 208 faces, only two CS+
 25 pairings (neutral faces) with the unpleasant UCS odor were enough to affect facial evaluations
 26 negatively. We now know that animals can associate aversive odors with visual objects in a fast
 27 and flexible manner (Handler et al., 2019). These findings show a similar capacity in humans
 28 to rapidly associate faces with aversive odors.

30 *Future directions*

31 In the review above, we have highlighted key results emerging from the literature on odor
 32 effects on face perception. Several avenues remain to be explored in further research. For
 33 example, only a few studies investigated how interindividual variation in odor sensitivity
 34 affected odor effects in facial perception. Individuals vary considerably in their odor

1 preferences, which might influence how different odors affect facial perception. For example,
2 people vary in disgust sensitivity (Tybur, Cinar, Karinen, & Perone, 2018), which might be
3 especially relevant for how unpleasant odors might affect perception of facial expressions.
4 Here, a newly developed body odor disgust scale might be a suitable instrument for
5 investigating individual differences in olfactory related disgust (BODS; Liuzza, Lindholm, et
6 al., 2017). Although the BODS was developed for measuring body odor related disgust, it has
7 excellent construct validity in relation to existing disgust scales and has been shown to predict
8 disgust responses to human sweat bio-samples (Liuzza, Olofsson, Sabiniewicz, & Sorokowska,
9 2017).

10
11 Nevertheless, individual variation is not only relevant for unpleasant odors. In our work, we
12 have observed that odors regarded as pleasant (e.g., lilac) might be perceived as unpleasant at
13 higher concentrations by some participants (Syrjänen, 2020; Syrjänen et al., 2018). Conversely,
14 an unpleasant odor such as valeric acid is by some participants rated as positively valenced (see
15 Figure 1 for a summary of valence ratings for these odors at three concentrations). Although
16 olfactory valence is sometimes thought of as a hard-wired response, perhaps universal
17 (Yeshurun & Sobel, 2010), our observations suggest this assumption may lead to an
18 underestimation of the individual variation in olfactory valence evaluations. Future work could
19 instead tailor specific odors for each participant to maximize valence effects.

20

Figure 1. Rated odor intensity and valence for three different concentrations of valeric acid (unpleasant) and lilac essence (pleasant). The black lines show the predicted linear relationship between intensity and valence. Uncertainty of the linear effect (colored lines) is visualized with a sample of draws from the posterior distribution. Figure reprinted with permission from the author.

Among the reviewed studies, many have used unpleasant, presumably disgusting odors and facial expressions such as angry or fearful that do not have a natural connection to these odors. This usage might reflect the fact that anger and fear are well investigated in affect perception research but that these emotions are not easily mapped onto the affective space of odors. Instead, we argue that the basic emotion most well-matched by unpleasant odors is disgust, and for pleasant odors, happiness (Bensafi, Rouby, et al., 2002; Croy et al., 2011; Glass et al., 2014). Future research should consider odors congruent with distinct emotional expressions, and this olfactory-visual congruency should be empirically validated. For example, odors such as smoke may elicit fear in specific contexts (Stevenson, 2010). Thus, the odor might modulate the processing of fearful expressions in a context-dependent way. Future studies might also explore the connection between odors and mood and how these relate to the perception of emotional expressions. Also, interindividual factors such as gender, age, and culture should be investigated in future research. These factors typically affect the perception of emotional information in other sensory modalities such as vision and hearing (Cortes, Laukka, Ebner, &

1 Fischer, 2019; Cortes, Laukka, Lindahl, & Fischer, 2017) and therefore probably also in the
2 context of different odors.

3
4 It is important to note that the studies reviewed here are not characterized by open research
5 practices such as transparent and preregistered study protocols and open data. In recent years
6 there has been an open debate within psychology due to the low reproducibility of research
7 findings (Open Science Collaboration, 2015). Transparent and open study protocols might also
8 reduce practices that result in non-replicable findings such as hypothesizing after results are
9 known (HARKing; Kerr, 1998). Considering that at least half of the studies utilized small
10 sample sizes and that odor effects typically may be assumed to be subtle, we can expect that
11 some of the findings in this area are false positives or negatives (Button et al., 2013). Almost
12 all studies found some effects of odor on facial perception. If we assume that many studies in
13 the field are underpowered, there might be a file drawer problem of conducted but not published
14 studies due to non-significant findings. The research in this area could also benefit from
15 standardized measures, testing procedures, and stimuli. Practices that have been highly
16 successful in emotion research include using standardized stimuli such as the international
17 affective picture set (IAPS; Lang, Bradley, & Cuthbert, 2008), and assessments such as the self-
18 assessment manikin (SAM; Bradley & Lang, 1994). Standardization would benefit the research
19 community by making it easier to compare results across studies and sustain an incremental
20 research endeavor.

21
22 Because of the relatively small number of published studies to date, open data would be
23 beneficial for the whole community of researchers. Open data practices will enable
24 reinterpretation and creation of novel hypotheses using existing data, and such practices will
25 reduce the need for duplications. On a positive note, the recent response from the olfactory
26 research community (www.gcchemosensr.org) with a large multinational study on olfactory
27 related changes in COVID-19 infection (Parma et al., 2020) might in the future be used as a
28 platform for large scale replication efforts.

30 *Conclusions*

31 We reviewed studies that span 25 years of olfactory research on odor effects on facial
32 perception. Generally, the results indicate that facial expressions are classified more rapidly in
33 the context of odors. Apart from a few studies that show face-odor valence congruency effects,

the most consistent finding is that valenced odors affect perceived face valence overall (e.g., faces are perceived as more unpleasant in an unpleasant odor condition). Rapid classification of faces is often unaffected by the congruency of face-odor pairings. However, there is some evidence that an odor's presence improves the response speed due to overall arousal effects. Establishing important individual differences markers and how odor effects may accumulate as a function of exposure time remain questions of importance for future work. More work on standardizing stimuli and experimental protocols and adopting open research practices may increase the robustness of results and might help address outstanding questions in this field.

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