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# Disgust sensitivity relates to affective responses to – but not ability to detect – olfactory cues to pathogens

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ABSTRACT

Hundreds of studies have assessed variation in the degree to which people experience disgust toward substances associated with pathogens, but little is known about the mechanistic sources of this variation. The current investigation uses olfactory perception and threshold methods to test whether it is apparent at the cue-detection level, at the cue-interpretation level, or both. It further tests whether relations between disgust sensitivity and olfactory perception are specific to odors associated with pathogens. Two studies (N's = 119 and 160) of individuals sampled from a Dutch university each revealed that pathogen disgust sensitivity relates to valence perceptions of odors found in pathogen sources, but not to valence perceptions of odors not associated with pathogens, nor to intensity perceptions of odors of either type. Study 2, which also assessed olfactory thresholds via a three-alternative forced-choice staircase method, did not reveal a relation between pathogen disgust sensitivity and the ability to detect an odor associated with pathogens, nor an odor not associated with pathogens. In total, results are consistent with the idea that pathogen disgust sensitivity relates to how olfactory pathogen cues are interpreted after detection, but not necessarily to the ability to detect such cues.

## 1. Introduction

When presented with the same stimulus – say, a fountain of vomit ejected from someone's mouth – different individuals experience different degrees of disgust (and, more precisely, different degrees of *pathogen* disgust). This variation, which is commonly referred to as pathogen disgust sensitivity (or, sometimes, disgust propensity; Van Overveld, De Jong, Peters, Cavanagh, & Davey, 2006), has drawn interest across multiple areas of the behavioral sciences due to its relation with anxiety disorders (e.g., Olatunji, Armstrong, & Elwood, 2017), dietary preferences (e.g., Çınar, Karinen, & Tybur, 2021), political sentiments (e.g., Billingsley, Lieberman, & Tybur, 2018), attitudes toward foreigners (e.g., Karinen, Molho, Kupfer, & Tybur, 2019), moral condemnation (e.g., Karinen & Chapman, 2019), and frequency of infection (Cepon-Robins et al., 2021) (see Inbar & Pizarro, 2021, and Tybur, 2021 for overviews). While substantial efforts have been dedicated to validating disgust sensitivity instruments (Karinen, Tybur, & de Vries, 2021; Olatunji et al., 2007; Olatunji et al., 2012), comparatively little work has sought to understand why individuals vary in disgust. This manuscript presents two studies that inform the mechanistic underpinnings of this variation.

### 1.1. The structure and function of pathogen disgust

Recent progress in understanding disgust has sketched out both its functions and the underlying mechanisms that execute those functions. Scholars have long recognized that many substances and behaviors that elicit disgust harbor the viruses, bacteria, and other micro-organisms that cause infectious disease (Angyal, 1941; Curtis & Biran, 2001; Rozin & Fallon, 1987). This observation – along with the fact that many of the action tendencies that accompany disgust (e.g., nausea, facial movements that limit points of entry for pathogen, avoidance of physical contact) – has led researchers to posit that pathogen disgust evolved to neutralize pathogens, whereas other types of disgust (e.g., toward incest;

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toward social transgressions) serve other functions (Al-Shawaf, Lewis, & Buss, 2018; Fessler & Navarrete, 2003; Fleischman, 2014; Lieberman & Patrick, 2018; Tybur, Lieberman, Kurzban, & DeScioli, 2013).

Some work has aimed to understand variation in disgust by considering its pathogen-avoidance function. These efforts have typically involved testing hypotheses that pathogen disgust sensitivity should be higher in ecologies with greater parasite stress and in individuals with greater susceptibility to infection (Fincher & Thornhill, 2012; Oaten, Stevenson, & Case, 2009). For example, one study reported greater pathogen disgust sensitivity in a nation with relatively high parasite stress (Ghana) than in a nation with relatively low parasite stress (the United States; Skolnick & Dzokoto, 2013). Another study of 23 nations found that pathogen disgust sensitivity is greater in nations with higher disease burdens (Hlay et al., 2021). However, the former study was limited by its comparison of only two nations, which can differ along a number of dimensions, and the latter study by its modest sample size ($N = 361$ total participants across those 23 countries recruited via Amazon Mechanical Turk) and a non-replication in a second study within the same paper. A study of over 11,000 participants across 30 nations did not detect a relation between disgust sensitivity and national parasite stress (Tybur et al., 2016), and another study of 284 individuals living in rural Bangladesh did not detect a relation between illness experienced during childhood and disgust sensitivity in adulthood (De Barra, Islam, & Curtis, 2014). Other research comparing disgust sensitivity across recently ill individuals versus those not recently ill – a method previously taken as revealing relations between infection vulnerability and efforts toward avoiding pathogens (e.g., Miller & Maner, 2011) – has not detected effects of illness recency on pathogen disgust sensitivity (Tybur, Jones, DeBruine, Ackerman, & Fasolt, 2020). A variety of other studies investigating the relation between progesterone, which putatively covaries with immune-suppressed states, have reported conflicting results (Fessler & Navarrete, 2003; Fleischman & Fessler, 2011; Jones et al., 2018; Miłkowska, Galbarczyk, & Jasienska, 2019; Miłkowska, Galbarczyk, Klimek, Zabłocka-Słowińska, & Jasienska, 2021; Stern & Shiramizu, 2022). In sum, evidence that pathogen disgust sensitivity is calibrated to vulnerability to infection or pathogen load in the ecology remains murky (Tybur, Çınar, Karinen, & Perone, 2018).

A complimentary approach has focused on the internal mechanisms underlying pathogen disgust (Tybur & Lieberman, 2016). To motivate a pathogen-neutralizing response, sensory systems must first detect features of the environment that correlate with pathogen presence. Examples of such features include the chemicals associated with bacterial contamination (e.g., in bodily wastes or spoiled foods), the moisture that facilitates bacterial growth, and the color and texture patterns associated with infectiousness in conspecifics (Curtis, Aunger, & Rabie, 2004; Curtis & Biran, 2001; Kreibig, 2010; Oum, Lieberman, & Aylward, 2011). Rather than reflexively leading to disgust, though, such cues are integrated with relevant aspects of an individual's current state and their relation to the source of the cues. For example, findings suggest that responses to pathogen cues might vary as a function of current sexual arousal (Borg & De Jong, 2012; Fleischman, Hamilton, Fessler, & Meston, 2015). Other work suggests that bodily fluids and wastes are less disgusting when they come from a highly-valued person, such as one's own baby relative to another person's baby, or a close friend or acquaintance relative to an enemy (Case, Repacholi, & Stevenson, 2006; Stevenson & Repacholi, 2005; Tybur, Lieberman, Fan, Kupfer, & de Vries, 2020). If pathogen disgust arises via multiple mechanisms, then trait-level variation in pathogen disgust could similarly reflect variation in how some (or all) of those mechanisms vary across individuals (Tybur et al., 2013). The current paper tests whether pathogen disgust sensitivity corresponds with variation in the ability to detect pathogen cues, with variation in affective responses to suprathreshold levels of those cues, or both.

### 1.2. Olfaction and disgust

Pathogen disgust can be elicited via all five senses. Consider again vomit, which can elicit disgust via its smell, feel, appearance, and taste, as well as the sound that accompanies its expulsion from a body or its impact with a surface. Of these five senses, olfaction offers perhaps the cleanest approach to assessing variation in the ability to detect such sensory features. Whereas the ability to detect the sight or sound of vomit emerges from lower-level thresholds for detecting features not specific to the stimulus (e.g., color, frequency), the ability to detect the smell of vomit can be isolated based on a few specific chemicals that give rise to disgust.

Although natural smells often arise from combinations of dozens or even hundreds of different molecules, just a single or few molecules can give rise to the characteristics of a particular odor. Some such molecules are produced as byproducts of microbial activity or digestive processes, such as when proteins, fats, and carbohydrates are broken down by microbes (McGee, 2020; Wood & Kelly, 2010). Some molecules correlate with the presence of infectious bacteria or viruses and the toxins produced by digestive processes (Olsson et al., 2014; Penn & Potts, 1998; Shirasu & Touhara, 2011). For example, low levels of isovaleric acid and butyric acid, both of which are present in vomit, are perceived as similar to the odor of real vomit (Herz & von Clef, 2001). Detection threshold for these molecules is usually very low, suggesting that humans are particularly sensitive to these olfactory cues to pathogens (Parma et al., 2017; Shirasu & Touhara, 2011). This sensitivity is perhaps not surprising given that olfaction partially functions to detect threats (Stevenson, 2010). Whereas most smells are not consciously noticed for most people, those that correspond with threats – especially infectious ones – immediately attract attention (Köster, Møller, & Mojet, 2014). At the same time, people differ substantially in their awareness of and ability to detect odors (e.g., Demattè et al., 2011; Majid, Speed, Croijmans, & Arshamian, 2017; Yee & Wysocki, 2001). These differences might coincide with those in disgust sensitivity (Tybur et al., 2013) – a possibility underscored by evidence suggesting that olfactory deficits increase contact with pathogens. For example, in a survey of 345 patients with clinically-assessed olfactory impairments, 75% of respondents reported having difficulties recognizing spoiled food (Miwa et al., 2001). Another survey of 340 impaired patients revealed ingestion of spoiled foods as the second most frequent hazard associated with olfactory disability (Santos, Reiter, DiNardo, & Costanzo, 2004).

### 1.3. Existing research on disgust and olfactory thresholds

A handful of studies have tested how pathogen disgust sensitivity relates to olfaction. We describe six of particular relevance here. First, a study of 56 men, who were categorized into normosmic (normal olfaction), hyposmic (impaired olfaction), and anosmic (severely impaired olfaction) groups based on an olfactory function battery, reported that olfaction-impaired individuals report more disgust toward poor hygiene, less disgust toward spoiled foods, and no difference in disgust toward death and bodily secretions (Ille, Wolf, Tomazic, & Schienle, 2016). Second, a study in which 123 individuals were split into high and low olfactory sensitivity groups based on ability to detect phenylethanol, a chemical compound found in roses (McGee, 2020), reported that groups of men categorized as high versus low on olfactory sensitivity differed in a measure of disgust sensitivity, but women across the two olfactory sensitivity groups did not (Croy et al., 2017). Third, each of two studies (N's = 39 and 37) did not detect a relation between pathogen disgust sensitivity and threshold to detect *n*-butanol, which has a mildly negative scent reminiscent of whiteboard marker ink (Chan, Holland, van Loon, Arts, & van Knippenberg, 2016). Fourth, a study of 60 individuals did not detect a relation between pathogen disgust sensitivity and thresholds to detect *n*-butanol or phenylethanol (Chan, van Dooren, Holland, & van Knippenberg, 2020). Fifth, a study of 162 individuals did not detect a relation between pathogen disgust

sensitivity and threshold to detect *n*-butanol (Prokosch, Airington, & Murray, 2021). Sixth, a study of 30 women pre-screened to be high on pathogen disgust sensitivity and 29 women pre-screened to be low on pathogen disgust sensitivity reported that the threshold to detect carbon disulfide, which smells likes some spoiled foods, relates to pathogen disgust sensitivity within the low pathogen disgust sensitivity group, but not in the high group (Schienle & Schöpf, 2017).

The studies reviewed above have only a limited ability to inform whether pathogen disgust sensitivity relates to abilities to detect pathogens. Those that did not detect a relation between olfactory thresholds and pathogen disgust sensitivity (Chan et al., 2016, 2020; Prokosch et al., 2021) assessed abilities to detect odors not typically present in pathogen sources. One of the two studies that did report a relation between olfactory thresholds and pathogen disgust sensitivity shares this limitation (Croy et al., 2017). The other detected a relation between pathogen disgust sensitivity and ability to detect an odor associated with pathogens, but only within a subgroup already screened to be low on pathogen disgust sensitivity (Schienle & Schöpf, 2017). These limitations largely result from the studies not having been designed to inform whether pathogen disgust sensitivity relates to the ability to detect odors specifically present in pathogen sources. For example, while *n*-butanol and phenylethanol are readily available via commercially available test batteries (e.g., Sniffin Sticks; Hummel, Sekinger, Wolf, Pauli, & Kobal, 1997), they are not likely candidates as cues to pathogens.

### 1.4. The current investigation

Multiple features of the current work were designed specifically to assess whether pathogen disgust sensitivity relates to affective reactions to and the ability to detect pathogen-relevant odors. First, we used multiple odors, some of which were selected because they are commonly found in pathogen sources, and others of which were selected because they are *not* commonly found in pathogen sources (and are generally perceived as neutral-to-pleasant). This approach allows for distinguishing between the possibilities that pathogen disgust sensitivity relates to perceptions of and abilities to detect odors *in general* versus those specifically associated with pathogens. Rather than using a commercially-available battery of odors, we manufactured olfactory stimuli tailored for this study. Second, we assessed both valence and intensity ratings of odors presented at suprathreshold levels (i.e., levels that should be detected by most individuals). Intensity ratings might reflect detection abilities, if individuals who perceive a suprathreshold concentration as more intense are better able to detect the cue, whereas valence ratings reflect motivations to avoid the stimulus. However, perceptions of intensity are not necessarily linearly related to abilities to detect molecules (Cain, 1969; Engen, 1964); indeed, how the olfactory system outputs perceptions of intensity remains mysterious (Koskinen & Tuorila, 2005; Mainland et al., 2014). Thus, in Study 2, in addition to assessing perceptions of odor intensity, we used a more valid method of assessing abilities to detect odors: the three-alternative forced-choice staircase procedure traditionally used in psychophysics (e.g., Cornsweet, 1962).

In Study 1, we presented all stimuli at suprathreshold levels, and we tested whether ratings of odor valence and intensity related to pathogen disgust sensitivity. Based on results from Study 1, we selected two odors – one associated with pathogen sources and one not – for threshold assessments in Study 2. Then, in Study 2, we again assessed whether pathogen disgust sensitivity relates to perceptions of odor valence and intensity (as a replication of Study 1), and we further tested whether it relates to the ability to detect both odors.

The current study had another goal that was not pre-registered: assessing the specificity of any relation between odor perceptions and the pathogen domain of the Three-Domain Disgust Scale (TDDS) (Tybur, Lieberman, & Griskevicius, 2009). The TDDS has two other domains: sexual and moral. If existing interpretations of the TDDS are correct, perceptions of pathogen-relevant odors should relate more strongly to the pathogen domain than to the sexual and moral domains. Notably, though, one recent study reported that sexual – rather than pathogen – disgust sensitivity, relates to olfactory acuity (i.e., the ability to distinguish between different odors) (Prokosch et al., 2021); the current work is able to assess whether sexual disgust sensitivity relates to the olfactory parameters assessed here. Further, the recently developed Body Odor Disgust Scale (BODS) (Liuzza et al., 2017) putatively assesses disgust specifically toward odors rather than toward pathogen cues more broadly. If existing interpretations of the BODS are correct, then odor perceptions should relate more strongly to the BODS than to the pathogen domain of the TDDS. We also included the germ aversion subscale of the Perceived Vulnerability to Disease scale (Duncan, Schaller, & Park, 2009), which has frequently been interpreted as assessing the same construct as the pathogen domain of the TDDS (Tybur, Frankenhuis, & Pollet, 2014), and the Highly Sensitive Person Scale (Aron & Aron, 1997), which putatively measures broad sensory-processing sensitivity. Study aims and procedures were pre-registered on the Open Science Framework, where all data and analysis scripts are also located (https://osf.io/3k49t/). The study was approved by the Scientific and Ethical Review Board of the Faculty of Behavioural and Movement Sciences at Vrije Universiteit Amsterdam.

## 2. Study 1

### 2.1. Participants

As pre-registered, we enrolled 119 individuals (90 women and 29 men, one of whom reported having transitioned from female to male, and was coded as male for analyses), who participated for either €7.50 or as an assignment for an introductory psychology course. We did not have an a priori expectation of the effect size of the relation between pathogen disgust sensitivity and valence or intensity perceptions of odors. The sample size was determined based on logistic constraints and its adequate (80%) power to detect bivariate correlations of $r = 0.25$ (two tailed). All participants were fluent in Dutch, all were below 40 years old ($M = 21.07$, $SD = 3.61$), and none were regular smokers. Study procedures took, on average, 45 minutes per participant. Participants were run one at a time. Data were collected in autumn 2018.

### 2.2. Materials

After consulting with multiple chemists and olfaction researchers, we identified five chemicals that are found in pathogen-containing substances and which we anticipated would be unpleasant (butyric acid, isovaleric acid, dimethyl trisulfide, trimethylamine, and hexanoic acid) and five that are not typically found in pathogen-containing substances and that we anticipated would be neutral to pleasant (linalyl acetate, alpha ionone, vanillin, phenylethanol, and citronellol). One additional stick included only triacetin, a virtually-odorless solvent used to dilute the 10 odors.

Odors were presented in sticks purchased from ETRA Weber GmbH (Königsbach-Stein, Germany). The sticks, which were 100.2 mm long and 7.7 mm in diameter, contained a cylindrical reservoir made of an absorbent material that can hold at least 1 mL of liquid. All odors were diluted in triacetin (see Table 1 for dilution values and descriptions of odors), and dilutions greater than 100× were made in multiple steps (see the online supplement for further details). In designing the study, we evaluated safety based on calculations of estimated chemical exposure during inhalation. We attended to multiple parameters, including air molar volume, odor molar mass, chemical concentration, pen volume, tip size, and exposure duration for each compound. Risk to participants was minimal given the duration of exposure and the diluted concentrations of the chemicals.

**Table 1**
Odor concentrations and descriptions for suprathreshold odorant stimuli.

| Component | Concentration Study 1 (mol/L) | Concentration Study 2 (mol/L) | Smell reminiscent of: |
|---|---|---|---|
| Butyric acid[1] | 2.00E-02 | 2.00E-03 | Vomit[†], feet[†], aged parmesan cheese[†] |
| Isovaleric acid[1] | 5.50E-02 | 3.3E-02 | Rancid cheese*, human sweat[†] |
| Dimethyl trisulfide[1] | 1.00E-06 | 1.00E-07 | Boiled vegetables[†], truffles[†] |
| Trimethylamine[1] | 3.00E-02 | 1.2E-03 | Pungent (rotten) fish*, stale urine[†] |
| Hexanoic acid[1] | 4.00E-05 | 4.00E-05 | Cheesy, rancid[†], sweat-like* |
| Linalyl acetate[1] | 2.00E-03 | 4.00E-03 | Lavender[†], bergamot[†], floral*, fruity* |
| Alpha ionone[1] | 2.50E-02 | 1.25E-02 | Violet*[†], intensely floral[†] |
| Vanillin[2] | 7.50E-02 | 7.50E-02 | Vanilla* |
| Phenylethanol[2] | 7.50E-02 | 7.50E-02 | Rose*[†], floral[†] |
| Citronellol[2] | 1.50E-02 | 1.50E-02 | Citrus[†], Lemon*, Herbal [†] |
| Triacetin[2] | – | – | Ethereal, fruity odor* |

*Note: [1]indicates that the component was supplied by Firmenich; [2]indicates that the component was purchased from Sigma; *According to PubChem; [†]according to* McGee (2020).

**Table 2**
Study 1 relations between pathogen disgust sensitivity and perceptions of individual odor valence and intensity.

| Odor | Valence | Intensity | $r_{ds,valence}$ | $r_{ds,intensity}$ |
|---|---|---|---|---|
| Butyric acid$_p$ | −2.56 (.56**) | 5.60 (.68**) | −.21* | .14 |
| Trimethylamine$_p$ | −2.74 (.52**) | 6.32 (.68**) | −.11 | .16 |
| Isovaleric acid$_p$ | −2.22 (.48**) | 4.93 (.51**) | −.15 | .13 |
| Dimethyl trisulfide$_p$ | −1.50 (.61**) | 4.64 (.65**) | −.14 | .04 |
| Hexanoic acid$_p$ | −1.05 (.48**) | 3.72 (.67**) | −.05 | .12 |
| Alpha ionone$_{np}$ | 2.10 (.68**) | 4.36 (.72**) | −.02 | .07 |
| Phenylethanol $_{np}$ | 1.06 (.56**) | 3.51 (.71**) | −.08 | −.06 |
| Vanillin$_{np}$ | 1.63 (.38**) | 3.23 (.56**) | −.03 | −.00 |
| Citronellol$_{np}$ | 1.27 (.63**) | 3.65 (.57**) | .16 | .08 |
| Linalyl acetate$_{np}$ | .63 (.14) | 2.73 (.47**) | −.14 | −.08 |
| Triacetin (blank stick) | .26 (.09) | 1.55 (.38**) | .03 | .03 |
| Composite pathogen-relevant | −2.02 | 5.03 | −.22* | .16 |
| Composite non-pathogen-relevant | 1.34 | 3.49 | −.03 | .00 |

Note: * Indicates statistical significance at $p < .05$, ** indicates $p < .01$; ds = pathogen disgust sensitivity; p subscripts indicate pathogen-relevant, and np subscripts indicate non-pathogen-relevant. Valence and intensity values per participant are averages across two ratings per odor. Numbers in brackets indicate the correlation between the two ratings per odor.

### 2.3. Procedures

Participants were escorted to a private room, where they provided informed consent and were given an overview of the study procedures. The room contained a rack holding the 11 sticks. Each stick was capped and labeled with a number. For the first part of the study, the researcher, while wearing gloves, briefly waved each stick under the participant's nose for 3 seconds and asked the participant to inhale. The participant verbally reported: (1) the odor's valence on a −4 (very unpleasant) to +4 (very pleasant) scale; (2) the odor's intensity on a 0 (I don't smell anything) to 9 (strongest I've ever smelled) scale; and (3) a free response description of the odor. After recording these answers, the researcher waited until 60 seconds had passed before presenting the next odor. This process was repeated until the participant had smelled each of the 11 sticks. Participants were randomly assigned to one of 10 presentation orders.

After smelling the 11 sticks, participants were escorted to a private cubical, where, via a Qualtrics survey on a computer, they completed four individual differences measures, each of which were presented in Dutch: the Three-Domain Disgust Scale (Tybur et al., 2009), the Perceived Vulnerability to Disease scale (Duncan et al., 2009), the Body Odor Disgust Scale[11] (Liuzza, Lindholm, et al., 2017), and the Highly Sensitive Person scale (Aron & Aron, 1997). They then completed the odor rating task again. The presentation order was different during the second ratings, and participants were not able to see the code labeling each stick.

### 2.4. Analytic approach

As pre-registered, we analyzed the data in two ways. First, we averaged across the two valence and intensity ratings for each stick within participants. We present mean ratings of valence and intensity for each odor, and we present bivariate correlations between pathogen disgust sensitivity and odor ratings (see Table 2). Second, we conducted multi-level analyses with random intercepts for participants and odors and random slopes for effects that could have varied across participants or odors.

### 2.5. Results

As expected, the odors varied in both their valence, $F(10, 1278) = 297.1$, $p < .001$, and their intensity, $F(10, 1278) = 73.82$, $p < .001$. All pathogen-relevant odors were, on average, rated on the negative half of the scale, and all non-pathogen-relevant odors were, on average, rated on the positive half of the scale. We detected a non-zero correlation between pathogen disgust sensitivity and valence ratings for only butyric acid (a pathogen-relevant odor), $r = -.21$, $p = .02$, and we detected no non-zero correlations between pathogen disgust sensitivity and any of the intensity ratings.

We then computed composites of valence and intensity ratings for the pathogen-relevant odors and non-pathogen-relevant odors. We detected a relation between pathogen disgust sensitivity and the aggregate of the five pathogen-relevant odor valence ratings, $r = -0.22$, $p = .015$, but not the aggregate of the five non-pathogen-relevant odor

[1] The BODS has an *internal* subscale (e.g., You are alone at home and notice that your feet smell strongly) and an *external* subscale with almost identical item content (e.g., You are sitting next to a stranger and notice that their feet smell strongly). Given the strong correlation between the two subscales ($r$ = 0.67, as reported by Liuzza, Lindholm, et al., 2017), we only administered the external subscale.

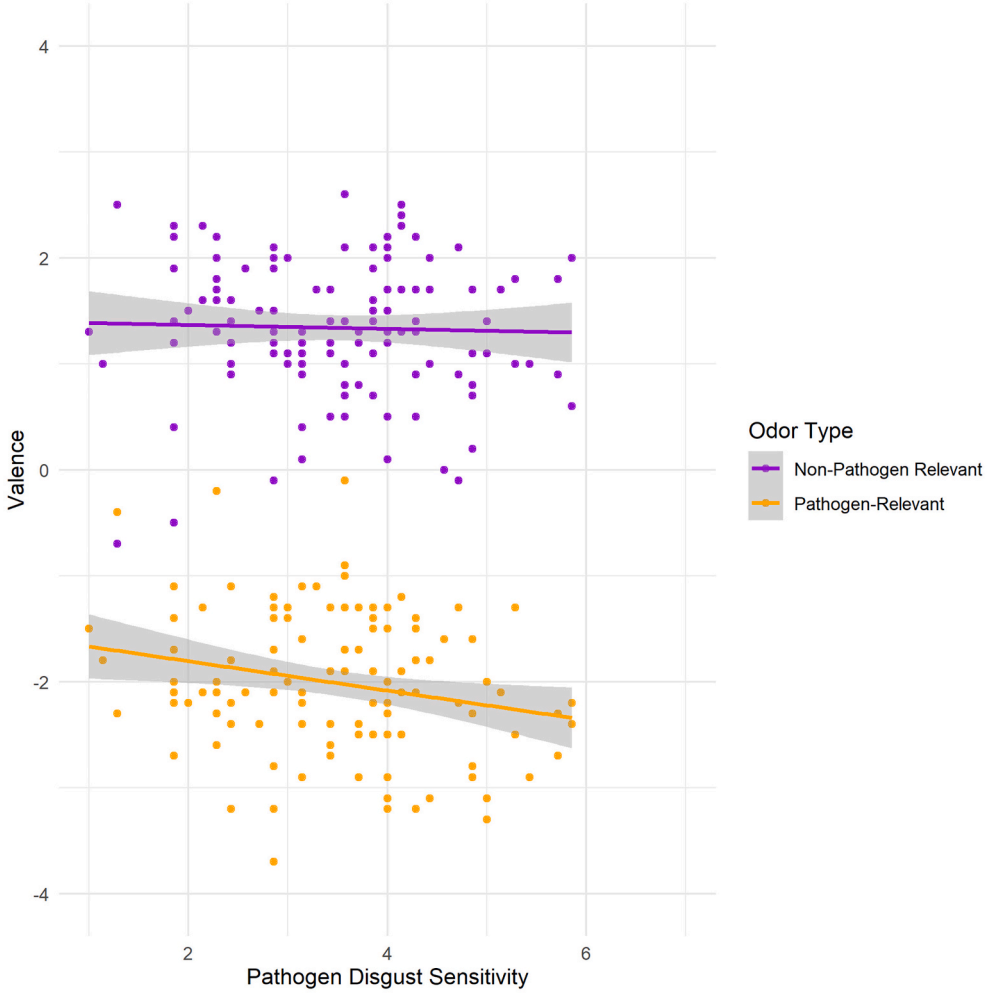


**Fig. 1.** Study 1 relations between pathogen disgust sensitivity and odor valence perceptions.
Note: Gray shading represents 95% confidence intervals around the regression lines.

valence ratings, $r = -0.034$, $p = .74$ (see Fig. 1). We did not detect relations between pathogen disgust sensitivity and intensity ratings for the pathogen-relevant odors, $r = 0.16$, $p = .09$, or non-pathogen-relevant odors, $r = 0.00$, $p = .98$.

As pre-registered, we next conducted a multilevel analysis specifying fixed effects for odor sequence (first versus second rating), odor category (positive versus negative), disgust sensitivity, and the interaction between odor category and disgust sensitivity, as well as random intercepts for participants and odors and random slopes for odor sequence (across both participants and odors) and disgust sensitivity (across odors). Random effects were removed if they did not improve model fit (judged via −2 log likelihood tests). Although we did not detect an interaction between pathogen disgust sensitivity and odor category, $F(1,10) = 4.39$, $p = .064$, simple effects were consistent with the bivariate correlations presented above; pathogen disgust sensitivity related to valence ratings for pathogen-relevant odors, $b = -0.14$, 95% CI [−0.26, −0.02], but not for non-pathogen-relevant odors, $b = -0.03$, 95% CI [−0.14, 0.09]. We followed the same procedures in examining intensity. Here, the main effect of pathogen disgust sensitivity was non-significant, $F(1,113) = 0.96$, $p = .33$, but the interaction with odor category was, $F(1, 9) = 8.64$, $p = .02$. As with the bivariate correlations, though, neither simple effect was significant (pathogen-relevant odors: $b = 0.20$, 95% CI [−0.05, 0.45]; non-pathogen-relevant odors: $b = 0.03$, 95% CI [−0.22, 0.28]).

Finally, we examined how pathogen-relevant odor valence related to sexual disgust sensitivity, moral disgust sensitivity, germ aversion, the Highly Sensitive Person Scale, and the Body Odor Disgust Scale. Three notable findings emerged. First, whereas pathogen disgust sensitivity related to valence ratings of pathogen-relevant odors, sexual and moral disgust sensitivity did not ($r$'s = −0.03 and −0.02, $p$'s = 0.71 and 0.85, respectively). Second, the magnitude of the correlation between the pathogen domain of the Three-Domain Disgust Scale and the Body Odor Disgust Scale was strong enough ($r = 0.75$) to suggest that the constructs assessed by these instruments are virtually identical. Third, pathogen-relevant odor valence ratings related similarly to body odor disgust sensitivity and pathogen disgust sensitivity, as well as to germ aversion and the Highly Sensitive Person Scale ($r$'s from −0.15 to −0.26, though the relation with germ aversion was non-significant; see Table 3).

### 2.6. Discussion

Study 1 provided preliminary evidence that pathogen disgust sensitivity relates to the degree to which olfactory cues to pathogens are perceived as unpleasant, but not the degree to which those same odors are perceived as intense. In contrast, we did not detect evidence that pathogen disgust sensitivity relates neither to pleasantness ratings nor intensity ratings of odors unrelated to pathogens. These findings have two implications. First, they suggest that any relation between pathogen disgust sensitivity and olfactory perception is specific to odors associated with pathogens. Second, they suggest that pathogen disgust sensitivity does not correspond with cue detection, but rather cue

**Table 3**
Study 1 means, standard deviations, and correlation coefficients with 95% confidence intervals.

| Variable | M | SD | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. Pathogen odor valence | −2.02 | .67 | | | | | | | | | |
| 2. Non-pathogen odor valence | 1.34 | .64 | .00 [−.18, .19] | | | | | | | | |
| 3. Pathogen odor intensity | 5.03 | 1.38 | −.56** [−.67, −.42] | .21* [.03, .38] | | | | | | | |
| 4. Non-pathogen odor intensity | 3.49 | 1.29 | −.33** [−.49, −.16] | .32** [.14, .47] | .81** [.74, .87] | | | | | | |
| 5. PDS | 3.52 | 1.08 | −.22* [−.39, −.05] | −.03 [−.21, .15] | .16 [−.03, .33] | −.00 [−.18, .18] | | | | | |
| 6. SDS | 2.74 | 1.42 | −.03 [−.21, .15] | −.06 [−.24, .12] | .00 [−.18, .19] | −.10 [−.27, .09] | .44** [.29, .58] | | | | |
| 7. MDS | 4.07 | .94 | −.02 [−.20, .16] | −.02 [−.20, .16] | .12 [−.06, .29] | .04 [−.14, .22] | .26** [.08, .42] | .32** [.15, .47] | | | |
| 8. BODS | 4.08 | 1.07 | −.26** [−.42, −.08] | .05 [−.13, .23] | .22* [.04, .38] | .07 [−.11, .25] | .75** [.66, .82] | .42** [.26, .56] | .33** [.16, .48] | | |
| 9. GA | 3.91 | .71 | −.15 [−.33, .03] | −.02 [−.20, .16] | .23* [.05, .39] | .13 [−.06, .30] | .28** [.11, .44] | .22* [.05, .39] | .04 [−.14, .22] | .25** [.07, .41] | |
| 1. HSPS | 4.45 | .71 | −.22* [−.38, −.04] | −.07 [−.24, .12] | .16 [−.02, .33] | .12 [−.06, .29] | .28** [.11, .44] | .10 [−.08, .28] | .22* [.05, .39] | .19* [.01, .36] | .14 [−.04, .31] |

*Note:* *M* and *SD* refer to mean and standard deviation, respectively. Values in brackets indicate 95% confidence intervals. *indicates $p < .05$. **indicates $p < .01$. Valence and intensity refer to composite ratings of five odors per category. PDS – Pathogen Disgust Sensitivity, SDS – Sexual Disgust Sensitivity, MDS – Moral Disgust Sensitivity, BODS – Body Odor Disgust Scale, GA – Germ Aversion, HSPS – Highly Sensitive Person Scale.

interpretation. This second implication carries a critical caveat: ratings of intensity might partially reflect how odors are interpreted rather than how well they are detected. Indeed, valence and intensity ratings correlated strongly for both pathogen-relevant odors, $r = -0.56$, and for those unrelated to pathogens, $r = 0.32$. Assessing whether pathogen disgust sensitivity corresponds with cue detection requires assessment of olfactory thresholds – an assessment executed in Study 2.

## 3. Study 2

### 3.1. Participants

As pre-registered, we enrolled 160 individuals (121 female), who participated in exchange for either €20 or credit in an introductory psychology class. This sample size affords 80% power to detect a bivariate correlation of $r = 0.22$ – the magnitude of the relation we observed between disgust sensitivity and the aggregate of the pathogen-relevant odors in Study 1. All participants were fluent in Dutch and younger than 40 years old ($M = 20.10$, $SD = 1.67$), and none were regular smokers. Study procedures took, on average, two hours per participant. Data were collected in spring 2019.

### 3.2. Materials

The same chemicals used in Study 1 were used for suprathreshold ratings of valence and intensity. Dilutions were adjusted slightly to reduce intensity ratings for some odors and increase intensity ratings for others (see Table S1). For threshold assessments, we used the odor that had the strongest bivariate relationship with pathogen disgust sensitivity in Study 1 (butyric acid) and phenylethanol, which is not associated with pathogens and is commonly used to assess general olfactory function (e.g., Reden, Draf, Frank, & Hummel, 2016). Both chemicals were semi-logarithmically diluted in different amounts of triacetin, leading to 36 different concentrations of butyric acid and 36 different concentrations of phenylethanol (see supplement for more details).

### 3.3. Procedure

Participants were invited into a private room, where they signed a consent form after receiving a description of the study procedures. After providing consent, they were escorted to a computer within a separate private cubical, where, via a Qualtrics survey, they provided demographic data (e.g., age, sex) and completed the same measures deployed in Study 1 (the Three-Domain Disgust Scale, the Perceived Vulnerability to Disease scale, the Body Odor Disgust Scale, and the Highly Sensitive Person Scale), as well as one additional measure included for exploratory purposes (the Aggression-Submission-Conventionalism Scale; Dunwoody & Funke, 2016). As in Study 1, all questionnaires were presented in Dutch.

After completing these instruments, participants returned to the private room, where the researcher had prepared the materials for the three-alternative forced-choice up-and-down threshold (staircase) assessment. The researcher put on odorless gloves, and the participant put on a blindfold. For the threshold task, we used a rack containing three rows and 24 columns. One row contained the sticks with odors, with concentrations increasing from left to right. The other two rows contained odorless sticks. An additional rack contained lower concentrations of each of the odors, which we intended to use if participants could detect even the lowest of the other 24 concentrations. None of these concentrations were required.

Three sticks (one target and two blanks) from a single column were used for each trial. The researcher held the first stick under the participant's nose for 3 seconds and stated the stick number (e.g., stick 1) and then presented sticks 2 and 3 in the same way. Presentation sequence (whether the stick containing the odor was presented first, second, or third) was randomized across trials, and each trial was followed by a 30-

second break intended to mitigate odor adaptation. After smelling the three sticks, the participant indicated which one contained the odor. If the participant failed to identify the correct stick, the next trial included the set of sticks containing the next higher odor concentration. If the participant identified the correct stick, the next trial included the same set of sticks. If the correct stick was identified a second time, the researcher proceeded to a lower concentration. This procedure continued until seven reversals (i.e., changes from increasing to decreasing concentrations, or vice-versa) were reached. As preregistered, the concentration for the final four reversals was averaged to estimate a participant's threshold. After the seven reversals, participants removed their blindfold and took a short break before repeating this procedure with the other odor. Odor order (i.e., butyric acid or phenylethanol first) was randomized across participants.

After finishing the threshold assessments, participants removed their blindfold. The researcher retrieved another rack, which contained the 11 sticks containing suprathreshold concentrations of the five sticks containing pathogen-relevant odors, five containing non-pathogen-relevant odors, and a single stick containing a neutral odor. The presentation order for the 11 sticks was randomized via a Qualtrics survey, which the researcher accessed via an iPad. The researcher waved the stick specified by the survey under the participant's nose for three seconds and asked the participant to inhale. Then, the researcher gave the iPad to the participant, who rated the odor's valence on a labeled magnitude scale ranging from −100 (*greatest imaginable unpleasantness*) to +100 (*greatest imaginable pleasantness*), and its intensity on a scale from 0 (*barely detectable*) to 100 (*strongest imaginable*). We used this response format (rather than the nine-point Likert-type scales used in Study 1) based on arguments that labeled magnitude scales afford finer-grained distinctions between high levels of olfactory experiences (Green et al., 1996). Participants then returned the iPad to the researcher, who proceeded to the next randomly-assigned stick and repeated the procedure after 30 seconds had passed. The procedure continued until the participant smelled and rated the contents of all 11 sticks twice.

### 3.4. Results

Consistent with Study 1, pathogen disgust sensitivity related to the aggregate valence rating of the five pathogen-relevant odors, $r = -0.27$, $p < .001$, but not to the aggregate valence ratings of the five non-pathogen-relevant odors, $r = -0.02$, $p = .77$ (see Fig. 2). Also consistent with Study 1, we did not detect a relation between pathogen disgust sensitivity and intensity ratings for either odor type, $r$'s = 0.09 and 0.03; $p$'s = 0.25 and $p = .71$ (see Table 4).

Multilevel analyses yielded similar results. For valence ratings, an interaction between pathogen disgust sensitivity and odor type (pathogen versus not) emerged, $F(1, 3069) = 20.75$, $p < .001$, with pathogen disgust sensitivity relating to valence ratings of pathogen-relevant odors, $b = -4.1$, 95% CI [−5.78, −2.41], but not non-pathogen-relevant odors, $b = -0.15$, 95% CI [−1.84, 1.53]. For intensity ratings, no interaction between pathogen disgust sensitivity and odor type emerged, $F(1, 3069) = 3.14$, $p = .08$, nor did a main effect of pathogen

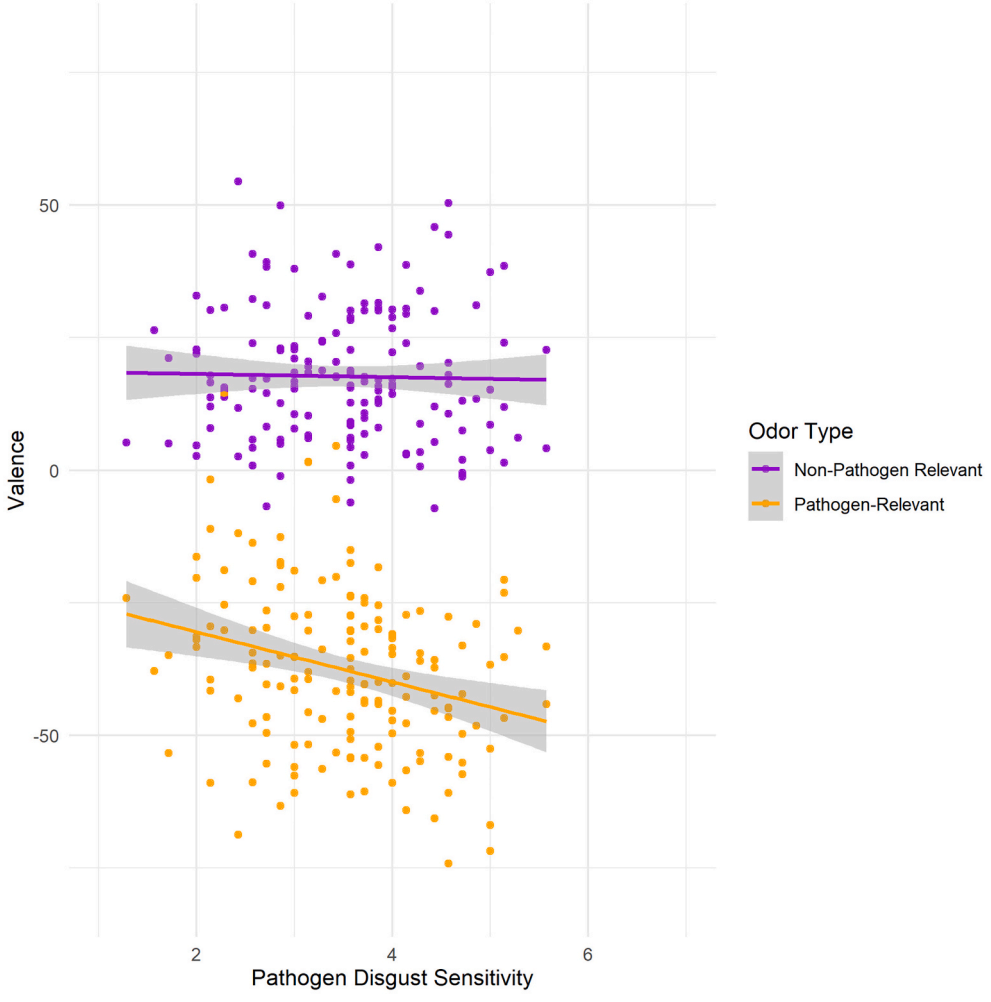


**Fig. 2.** Study 2 relations between pathogen disgust sensitivity and odor valence ratings.
Note: Gray shading represents 95% confidence intervals around the regression line.

**Table 4**
Study 2 relations between pathogen disgust sensitivity and perceptions of individual odor valence and intensity.

| Odor | Valence | Intensity | $r_{ds,valence}$ | $r_{ds,intensity}$ |
|---|---|---|---|---|
| Butyric $acid_p$ | −38.23 (.41**) | 35.44 (.57**) | −.15 | .08 |
| $Trimethylamine_p$ | −5.61 (.69**) | 46.80 (.68**) | −.30* | .09 |
| $Isovaleric\ acid_p$ | −37.44 (.32**) | 34.70 (.43**) | −.15 | .12 |
| $Dimethyl\ trisulfide_p$ | −44.95 (.51**) | 46.14 (.65**) | −.16* | −.01 |
| $Hexanoic\ acid_p$ | −16.71 (.40**) | 22.80 (.42**) | −.08 | .05 |
| $Alpha\ ionone_{np}$ | 29.36 (.48**) | 24.52 (.57**) | .05 | .08 |
| $Phenylethanol_{np}$ | 13.10 (.38**) | 15.61 (.60**) | −.09 | .02 |
| $Vanillin_{np}$ | 8.26 (.32**) | 1.30 (.24**) | −.00 | −.04 |
| $Citronellol_{np}$ | 13.80 (.37**) | 13.89 (.29**) | −.12 | −.11 |
| $Linalyl\ acetate_{np}$ | 23.92 (.50**) | 26.59 (.60**) | .06 | .07 |
| Triacetin (blank stick) | 6.54 (.14) | 1.72 (.23**) | −.01 | .00 |
| Composite pathogen-relevant | −37.59 | 37.18 | −.27* | .09 |
| Composite non-pathogen-relevant | 17.69 | 18.18 | −.02 | .03 |

Note: * Indicates statistical significance at $p < .05$, ** indicates $p < .01$; ds = pathogen disgust sensitivity; p subscripts indicate pathogen-relevant, and np subscripts indicate non-pathogen-relevant. Valence and intensity values per participant are averages across two ratings per odor. Numbers in brackets indicate the correlation between the two ratings per odor.

disgust sensitivity, $F(1, 161) = 0.84$, $p = .36$.

We next examined olfactory thresholds. Phenylethanol thresholds were related to suprathreshold phenylethanol intensity ratings, $r = 0.19$, $p = .013$, and valence ratings, $r = 0.15$, $p = .049$, meaning that individuals better able to detect phenylethanol rated suprathreshold levels as more pleasant and more intense. However, phenylethanol thresholds were unrelated to butyric acid intensity and valence ratings ($r$'s = 0.05 and 0.02, $p$'s = 0.57 and 0.80, respectively). Conversely, butyric acid thresholds were related to supratheshold butyric acid intensity ratings, $r = 0.20$, $p = .01$ – meaning that individuals better able to detect butyric acid rated suprathreshold levels as more intense – though not to butyric acid valence ratings, $r = -0.09$, $p = .26$, nor to phenylethanol intensity ratings or valence ratings ($r$'s = 0.03 and −0.02, $p$'s = 0.71 and 0.79, respectively). Critically, pathogen disgust sensitivity was unrelated to both butyric acid and phenylethanol thresholds, $r = -0.08$, $p = .29$, and, $r = -0.07$, $p = .36$. No conclusions changed when we log-transformed threshold values (see supplement for further details).

Finally, and as in Study 1, we compared how various disgust sensitivity measures related to pathogen-relevant odor valence perceptions and to each other (see Table 5). Again, the relation between pathogen disgust sensitivity and body odor disgust sensitivity suggested almost complete overlap between the constructs, $r = 0.77$. These two variables related similarly to valence ratings of pathogen-relevant odors ($r$'s = −0.27 and −0.23 for pathogen disgust sensitivity and body odor disgust sensitivity, respectively). As in Study 1, the relation between germ aversion and valence ratings of pathogen-relevant odors was non-significant, $r = -0.06$. And, similar to Study 1, pathogen disgust sensitivity related more strongly to pathogen-relevant odor valence ratings than did sexual disgust sensitivity ($r = -0.16$) and moral disgust sensitivity ($r = -0.01$) (though, unlike in Study 1, the 95% confidence interval for the relation with sexual disgust sensitivity overlapped with that with pathogen disgust sensitivity).

### 3.5. Discussion

Results from Study 2 again indicated that pathogen disgust sensitivity relates to the degree to which pathogen-relevant odors – but not non-pathogen-relevant odors – are perceived as unpleasant; they also did not reveal relations between pathogen disgust sensitivity and perceptions of odor intensity, regardless of odor type. And, critically, results did not reveal a relation between pathogen disgust sensitivity and the ability to detect a pathogen-relevant odor nor a non-pathogen-relevant odor.

## 4. Discussion

The tendency to experience disgust toward pathogen cues is stable across time, detectable by others, and distinct from both broader personality dimensions and tendencies to experience disgust in the sexual and moral domains (Tybur, 2021). Why people vary on this trait has been an outstanding question for decades. Most efforts in this area have tested hypotheses motivated by considerations of function, largely positing that pathogen disgust sensitivity is calibrated to an individual's vulnerability to infection. The current study used a complementary, mechanistic approach by examining whether pathogen disgust sensitivity is apparent at the level of cue detection (ability to detect olfactory pathogen cues) or cue interpretation (motivational responses after those cues are detected). Results suggested that pathogen disgust sensitivity relates to perceptions of the pleasantness of standardized suprathreshold levels of specifically pathogen-relevant odors, but not abilities to detect pathogen-relevant or non-pathogen-relevant odors (nor perceptions of the intensity of those odors). These findings accord with other studies that have not detected a relation between pathogen disgust sensitivity and abilities to detect other non-pathogen-relevant odors (e.g., Chan et al., 2016, 2020; Prokosch et al., 2021).

Ultimately, results do not reveal support for the hypothesis that pathogen disgust sensitivity reflects variation in the ability to detect pathogen cues (Tybur et al., 2013) – at least not those examined here. In concert with mixed findings regarding how pathogen disgust sensitivity relates to ecological parasite stress (Hlay et al., 2021; Tybur et al., 2016) and vulnerability to infection (Jones et al., 2018; Miłkowska et al., 2019, 2021; Tybur, Jones, et al., 2020), and findings that within-family similarities in pathogen disgust sensitivity are accounted for by genetic factors rather than shared environmental ones (Tybur, Wesseldijk, & Jern, 2020; cf. Widen & Olatunji, 2016), the sources of variation in pathogen disgust remain largely mysterious.

### 4.1. Implications regarding distinctions between disgust instruments

In each of two studies, valence ratings of pathogen-relevant odors related to the pathogen domain of the Three-Domain Disgust Scale, but not the moral domain. These findings are in line with myriad others revealing distinct relations between different types of disgust elicitors and, for example, broad personality domains (Karinen et al., 2021), political attitudes (Billingsley et al., 2018), and psychopathology (Olatunji et al., 2012). They also offer a novel validation of the Three-Domain Disgust Scale. Given that the odors administered to participants were unlabeled, and given that rating scales differed across the self-report instrument (not at all to extremely disgusting) and odor ratings (unpleasant to pleasant), method effects are unlikely to have influenced the relation between pathogen disgust sensitivity and valence ratings of pathogen-relevant odors (cf. Herz & von Clef, 2001). This interpretation is further supported by the fact that pathogen disgust sensitivity did not relate to valence ratings of odors that are not typically

**Table 5**
Study 2 means, standard deviations, and correlation coefficients with 95% confidence intervals.

| Variable | *M* | *SD* | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. Pathogen odor valence | −37.59 | 15.54 | | | | | | | | | | | |
| 2. Non-pathogen odor valence | 17.69 | 12.28 | −.09 [−.24, .07] | | | | | | | | | | |
| 3. Pathogen odor intensity | 37.18 | 12.85 | −.45** [−.57, −.32] | .25** [.10, .39] | | | | | | | | | |
| 4. Non-pathogen odor intensity | 18.18 | 8.08 | −.24** [−.38, −.08] | .56** [.45, .66] | .63** [.52, .71] | | | | | | | | |
| 5. Pathogen odor threshold | 4.19 | 3.23 | −.12 [−.27, .03] | −.06 [−.21, .09] | .16* [.01, .31] | .08 [−.07, .23] | | | | | | | |
| 6. Non-pathogen odor threshold | 8.98 | 2.92 | .04 [−.12, .19] | −.07 [−.23, .08] | .02 [−.13, .18] | .06 [−.10, .21] | .10 [−.06, .25] | | | | | | |
| 7. PDS | 3.51 | .90 | −.27** [−.41, −.12] | −.02 [−.18, .13] | .09 [−.06, .24] | .03 [−.13, .18] | −.08 [−.23, .07] | −.07 [−.22, .08] | | | | | |
| 8. SDS | 2.42 | 1.15 | −.16* [−.31, −.00] | −.06 [−.21, .10] | −.01 [−.16, .14] | −.04 [−.20, .11] | .10 [−.05, .25] | .05 [−.11, .20] | .15 [−.01, .30] | | | | |
| 9. MDS | 3.77 | .89 | −.01 [−.17, .14] | .04 [−.12, .19] | .02 [−.13, .17] | −.01 [−.17, .14] | .07 [−.09, .22] | .05 [−.10, .21] | .00 [−.15, .16] | .26** [.11, .40] | | | |
| 1. BODS | 4.17 | 1.10 | −.23** [−.37, −.08] | .02 [−.13, .18] | .17* [.01, .31] | .03 [−.12, .19] | −.10 [−.25, .06] | −.09 [−.25, .06] | .77** [.70, .83] | .12 [−.04, .26] | .06 [−.10, .21] | | |
| 11. GA | 3.50 | 1.02 | −.06 [−.21, .10] | .02 [−.14, .17] | .04 [−.12, .19] | .01 [−.15, .16] | −.02 [−.17, .14] | .04 [−.11, .20] | .46** [.33, .58] | .21** [.06, .35] | .09 [−.07, .24] | .43** [.30, .55] | |
| 12. HSPS | 4.39 | .80 | −.21** [−.35, −.05] | −.09 [−.24, .07] | .13 [−.03, .27] | −.01 [−.17, .14] | .01 [−.14, .17] | −.05 [−.20, .11] | .38** [.24, .51] | .20* [.04, .34] | −.08 [−.24, .07] | .32** [.17, .45] | .45** [.32, .56] |

*Note:* *M* and *SD* refer to mean and standard deviation, respectively. Values in brackets indicate 95% confidence intervals. *indicates $p < .05$. **indicates $p < .01$. Valence and intensity refer to composite ratings of five odors per category. Pathogen and Non-Pathogen thresholds refer to thresholds for butyric acid and phenylethanol, respectively. PDS – Pathogen Disgust Sensitivity, SDS – Sexual Disgust Sensitivity, MDS – Moral Disgust Sensitivity, BODS – Body Odor Disgust Scale, GA – Germ Aversion, HSPS – Highly Sensitive Person Scale. Higher threshold values refer to higher dilutions, indicating a better ability to detect the odor.

found in pathogen sources.

In contrast, we observed little distinction between how odor valence ratings relate to the pathogen domain of the Three-Domain Disgust Scale versus a recently-developed measure designed to specifically assess disgust toward odors – the Body Odor Disgust Scale (Liuzza, Lindholm, et al., 2017). This result should perhaps not be surprising, since correlations between the two measures exceeded $r = 0.75$ (cf. Liuzza, Olofsson, Sabiniewicz, & Sorokowska, 2017). At the same time, the relation between pathogen-relevant odor valence ratings and the germ aversion factor of the Perceived Vulnerability to Disease Scale (Duncan et al., 2009) was non-significant in both studies (and, in Study 2, the 95% confidence interval for that relation did not overlap with the relation between pathogen disgust sensitivity and pathogen-relevant odor valence ratings). Hence, while germ aversion and pathogen disgust sensitivity are often used interchangeably in the behavioral immune system literature (e.g., Terrizzi Jr, Shook, & McDaniel, 2013; Tybur et al., 2014), they appear to differ in their relation to olfactory perception.

We detected a non-zero relation between sexual disgust sensitivity and valence ratings of pathogen-relevant odors in Study 2 ($r = -0.16$), but not in Study 1 ($r = -0.03$), though 95% confidence intervals for each study included point estimates from the other study. Sexual disgust sensitivity did not relate to any other measures of olfactory function across the two studies. Another recent study reported that sexual disgust sensitivity relates to the ability to discriminate between different scents, but not the ability to detect one odor (*n*-butanol) or the ability to correctly identify the nature of scents (Prokosch et al., 2021). At this point, it is unclear which dimensions of olfactory functioning relate to sexual disgust sensitivity, nor is it clear why such a relation might exist. Future work can inform these issues.

### 4.2. Limitations and future directions

We note a few limitations. First, although Study 2 was among the largest to investigate the relation between disgust sensitivity and olfactory perception, and it afforded 80% power to detect an effect size of $r = 0.22$ (two tailed), it had low power to detect smaller effect sizes (e.g., 24% power to detect $r = 0.10$, two tailed). Naturally, we cannot rule out a Type II error in this study, especially for small effect sizes. Second, although we used a larger number of olfactory stimuli than what is standard in this literature, this number was limited to 10 monomolecular odors, five of which were pathogen related, and five of which were not related to pathogens. Further, we only used two odors in our olfactory threshold assessment. Future work could address both of these limitations via a multi-lab collaboration, which would allow for a wider range of odors (as well as odor mixtures) and a larger sample size. Third, all pathogen-relevant odors used here were subjectively experienced as unpleasant, but not all unpleasant odors are necessarily associated with microbial threats. Others can be indicative of other types of threat, including those posed by predators and toxins (Hofer, Chen, & Schaller, 2020; Stevenson, 2010). Future work can evaluate whether pathogen disgust sensitivity also relates to affective responses to these types of odors (though, notably, such odors often lead to pain, irritation, fear, or anxiety rather than disgust). Fourth, odor thresholds were approximations based on an odorant's concentration within a liquid. The stimulus presented to the nose is the concentration of volatiles in the air, which evaporate from the liquid absorbed through the stimulus pen. Odor threshold values assessed here should be treated as approximations of what more precise methods (e.g., gas chromatography) would reveal (Tsukatani, Miwa, Furukawa, & Costanzo, 2003). Fifth, findings concerning the relation between pathogen disgust sensitivity and ability to detect pathogen cues might not generalize to other senses. That said, abilities to detect other types of cues (e.g., visual) are difficult to assess independent of lower-level properties (e.g., coloration). Nevertheless, future work could attempt to develop threshold detection methods for pathogen cues using other sensory modalities. For example, Ruisch,

Anderson, Inbar, and Pizarro (2020) recently detected relations between disgust sensitivity and both taste intensity perceptions of the bitter chemical 6-n-propylthiouraci (PROP) and a proxy for taste receptors on the tongue. Similar approaches could be used to assess how disgust sensitivity relates to a broader range of flavors (e.g., sour) and thresholds to detect those flavors. Sixth, we sampled from only one location in an ecology with a relatively low infectious-disease burden. Environmental pressures, including infectious-disease burden, pollution, or culturally-specific experiences (cf. Majid et al., 2017) can produce differences in olfactory sensitivity, either broadly (Sorokowska, Sorokowski, & Frackowiak, 2015; though see Hoover, Botescu, Fedurek, Aarts,& Berbesque, 2020 and Arshamian et al., 2022), or for specific substances (e.g., Zhou, Jiang, He, & Chen, 2010). Abilities to detect specific odors might also vary as a function of an odor's ecological relevance (Li et al., 2021). At the same time, between-population genetic differences may produce functional differences in olfaction, including detection ability (e.g., Hasin-Brumshtein, Lancet, & Olender, 2009; Mainland, Lundström, Reisert, & Lowe, 2014; Trimmer et al., 2019). Ultimately, given these issues, we cannot rule out the possibility that populations with different ecological affordances or genotype distributions might show different relations between pathogen disgust sensitivity and olfactory perception and ability. Future work could examine such relations in ecologies with higher infectious disease burdens, just as some work has tested how disgust sensitivity covaries with infection history in such ecologies (e.g., Cepon-Robins et al., 2021; De Barra et al., 2014).

### 4.3. Concluding thoughts

The last decade has seen important progress in the understanding of human pathogen-avoidance psychology (Ackerman, Hill, & Murray, 2018; Lieberman & Patrick, 2018; Murray & Schaller, 2016; Tybur et al., 2013), and much work during this period has aimed to illuminate why people vary in their tendency to experience disgust. The present results did not reveal evidence consistent with one hypothesis: that this variation results from variation in the ability to detect cues to pathogens. Moving forward, this research area could incorporate considerations of how the experience of disgust partially arise from the fitness affordances of a potential infection threat. For example, people are much less comfortable engaging in microbe-sharing acts with strangers likely to exploit them relative to strangers likely to cooperate with them (Tybur, Lieberman, et al., 2020), and mothers are less averse to the smell of their own baby's feces than the smell of another baby's feces (Case et al., 2006). Hence, disgust emerges not only from mechanisms specialized for pathogen detection, but also from those that estimate and store other fitness-relevant information. The same might apply at the individual differences level. Rather than reflecting only ability to detect pathogen cues or investment in avoiding pathogens, much of the variation trait pathogen disgust might reflect the pursuit of outcomes that require some exposure to pathogens (e.g., Bradshaw, Gassen, Prokosch, Boehm, & Hill, 2022; Sparks, Fessler, Chan, Ashokkumar, & Holbrook, 2018). Future investigations into these and other mechanistic underpinnings of pathogen disgust can shed further light on why people vary in their tendency to experience that disgust.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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## Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.evolhumbehav.2022.04.006.

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