The smoke-detector principle of pathogen avoidance: A test of how the behavioral immune system gives rise to prejudice (stage 1 registered report)

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Declarations of interest: none.

Abstract

Motivations to avoid infectious disease seem to influence prejudice toward some groups, including groups not explicitly associated with infectious disease. The standard explanation relies on signal detection theory and proposes that pathogen detection should be biased toward making many false alarms (false positives) and few misses (false negatives). Therefore, pathogen detection mechanisms arguably categorize a broad array of atypical features as indicative of infection, which gives rise to negative affect toward people with atypical features. We will test a key hypothesis derived from this explanation: specific appearance-based prejudices are associated with tendencies to make false alarms when estimating the presence of infectious disease. While this hypothesis is implicit in much work on the behavioral immune system and prejudice, direct tests of it are lacking and existing relevant work contains important limitations. We will conduct a cross-sectional study with a large US sample that includes measures of tendencies to make false alarms and prejudice toward multiple relevant social groups/categories.

Key words: prejudice; disgust; infectious disease; face perception; signal detection theory

1. Introduction

1.1. A link between prejudice and pathogen avoidance

Some social prejudices appear to result from motivations to avoid infectious disease (Oaten et al., 2011; Van Leeuwen et al., 2023). At least three kinds of relations between prejudice and pathogens have been observed: (1) some groups that are targets of prejudice (e.g., drug addicts, ethnic outgroups in some situations) are explicitly associated with infectious disease (Kurzban & Leary, 2001; Oaten et al., 2011); (2) some groups that are targets of prejudice (e.g., people with obesity, homeless people) evoke disgust, an emotion that motivates the avoidance of pathogens (Clifford & Piston, 2017; Inbar & Pizarro, 2021; Park et al., 2007; Vartanian, 2010); (3) individuals who are more worried about infectious disease (or are more disgust sensitive) are more prejudiced toward some groups, such as immigrants (Aarøe et al., 2017; Clifford et al., 2022; Ji et al., 2019) and gay men (Kiss et al., 2020; van Leeuwen et al., 2022). These observations demand an explanation: Why is there a link between infectious disease and prejudice?

1.2. Explanations of appearance-based prejudice

The relation between pathogen avoidance and appearance-based prejudice can be explained using concepts from signal detection theory. Like other hazards, identifying pathogen risks constitutes a signal detection problem (Park et al., 2003; Schaller & Park, 2011). People can respond to some stimulus as if a pathogen risk is present or as if it is absent. Responding as if a pathogen risk is absent when it is present constitutes an error, as does responding as if a pathogen risk is present when one is absent. A widespread assumption is that the latter (false positives) are generally less costly than the former (false negatives) (Haselton & Nettle, 2006; Oaten et al., 2011; Schaller & Park, 2011). Hence, mechanisms specialized for pathogen detection should be calibrated to make false positives more so than false negatives (Haselton & Nettle, 2006; Nesse, 2005). This reasoning leads to the following general hypothesis: people should be more likely to act as if non-contagious people are contagious than they are to act as if contagious people are non-contagious. Just as smoke detectors frequently go off when no fires are present, people are expected to frequently treat other humans as infection risks when those others do not pose such risks. This idea has been derived from error management theory (Haselton & Nettle, 2006) and the smoke detector principle of defense regulation (Nesse, 2005) and has been central in explaining the relation between infectious disease and prejudice.[1]

Multiple studies have argued that pathogen detection mechanisms categorize a broad array of atypical features or deviance from expected phenotypes as indicative of infection, just as a smoke detector categorizes a broad set of particles as indicative of a fire (Oaten et al., 2011; Park et al., 2007; Petersen, 2017; Schaller et al., 2003). Schaller and Park (2011, pp. 100-101) provided the following explanation of how false-positive errors may give rise to prejudice:

> Plus, because of the smoke-detector principle, there is another pernicious implication as well: Psychologically similar prejudicial responses may be aroused by the perception of people who aren't actually suffering from any infectious disease but who are simply characterized by some superficial anomaly in physical appearance… Consistent with this general hypothesis, a body of evidence now implicates the behavioral immune system as a contributing cause of prejudices against people whose physical appearance seems anomalous. The perceived threat of infection predicts more strongly prejudicial responses against people with physical disabilities, against people who are obese, and against people who are elderly…These findings illuminate a single subtle psychological process that contributes to a wide variety of appearance-based prejudices.

While this account may explain some types of prejudice, it does not provide a comprehensive explanation of all observed links between pathogen avoidance and prejudice. For example, numerous studies have observed relations between pathogen avoidance motivations and prejudice toward ethnic outgroups, immigrants, and gay men

[1] Note that neither error management theory nor the smoke detector principle necessarily make this prediction, they do so only with the assumption that during human evolution false positives about pathogen risk were less costly than false negatives.

(Aarøe et al., 2017; Clifford et al., 2022; Faulkner et al., 2004; Kiss et al., 2020). For these groups (and possibly other groups as well), the processes seem more complex due to social learning or social influence. First, people sometimes associate outgroups with infectious disease, because of socially shared information that a group is likely to pose an infection risk (Ji et al., 2019; Oaten et al., 2011). In such cases, we do not need the smoke-detector principle to explain why pathogen avoidance motivations relate to prejudice. Second, some outgroups are characterized by different norms. While some work proposed that pathogen avoidance motivations might trigger aversion toward people with different, foreign, norms (Faulkner et al., 2004), recent work suggests that such relations might be due to perceptions of low interpersonal value (Tybur et al., 2020; Van Leeuwen et al., 2023). Third, the causal order may sometimes be reversed--i.e., people may use the language of disease to evoke disgust toward an outgroup, thus communicate that the outgroup is not valued, and so mobilize people against that outgroup (Oaten et al., 2011).

Furthermore, there are multiple other theories that provide an explanation for the relation between infectious disease and prejudice. We briefly discuss four other accounts. First, Oaten et al. (2011) built on error management theory and proposed that various stigmas are the result of a three-component system that regulates pathogen avoidance. In short, a disgust component motivates avoidance, an atypicality detector orients attention to possible disease-related features, and a cognitive system enables using labels and explicit knowledge (e.g., germ theory). The interplay of these three components can explain numerous phenomena related to stigmatization of various minority groups and the avoidance of individuals who are associated (either implicitly or explicitly) with infectious disease. While the three-component model assumed that the logic of error management theory applies to pathogen avoidance, this assumption seems not essential to it. In other words, the proposal that stigmatization is the result of an interplay between these three components, is independent from whether the resulting behavior is biased toward false alarms or misses.

Second, some work has proposed that pathogen avoidance gives rise to assortative sociality, i.e., ethnocentric preferences to interact with (familiar) ingroup members and/or xenophobic preferences to avoid interactions with (foreign) outgroup members (Fincher & Thornhill, 2012; Thornhill & Fincher, 2014). While some work is supportive (Faulkner et al., 2004; Navarrete et al., 2007; Navarrete & Fessler, 2006), other studies have found no support for this account (Fan et al., 2022; Makhanova et al., 2022; van Leeuwen & Petersen, 2018).

Third, the affordance management approach to social perception holds that people seek to manage the opportunities that threats that other pose to them and that this can lead to prejudice, stigma, and discrimination (Krems & Neuberg, 2022; Pirlott & Cook, 2018). This approach can account for relations between pathogen avoidance and prejudice, in general that people who are motivated to avoid infectious disease express negative attitudes towards individuals and groups (e.g., gay men) that they (correctly or incorrectly) associate with infectious disease (Pirlott & Cook, 2018). The approach does not include the specific hypothesis that the smoke-detector principle gives rise to appearance-based prejudices, because it does not contain the assumption that various anomalous appearances will be responded to as if they were pathogen cues. In contrast, the approach emphasizes that observers have goals and seek information about how other individuals could enable or hinder the pursuit of their current goals. This typically points to different hypotheses, for example that aversion to obesity depends more on body-shape (i.e., the location of fat tissue) than on the amount of fat (Krems & Neuberg, 2022).

Fourth, a large amount of research has tried to understand the emotion disgust and how it influences social phenomena, such as prejudice, moral judgment, and political ideology. In a recent review, Inbar and Pizarro (2021) made a broad distinction between pathogen-avoidance accounts and extended-disgust accounts of disgust. In short, the former holds that disgust influences social judgments because disgust is an evolved pathogen-avoidance mechanism (Curtis et al., 2011; Oaten et al., 2009), while the latter holds that disgust influences social judgments because it has a broad function, is elicited by a broader range of stimuli, and helps address a range of threats, for example social disorder, spiritual impurity, reminders of humans' animal nature, and moral violations (Chapman et al., 2009;

Hodson et al., 2013; Rozin & Haidt, 2013). Overall, the currently available evidence about the effects of disgust on social judgments is more in line with the pathogen avoidance account than the extended disgust account (Inbar & Pizarro, 2021). The pathogen-avoidance account of disgust is compatible with the explanation of appearance-based prejudice built around the smoke-detector principle.

1.3. Limitations of existing evidence

There is substantial evidence that pathogen avoidance motivations contribute to prejudice towards some social categories, including people with obesity (Park et al., 2007; Tapp et al., 2020), elderly people (Duncan & Schaller, 2009; Nicol et al., 2021), people with physical disabilities (LoBue et al., 2022), people with facial disfigurements (Ryan et al., 2012), gay men (Kiss et al., 2020; Pirlott & Cook, 2018; van Leeuwen et al., 2022), and immigrants (Aarøe et al., 2017; Clifford et al., 2022; Faulkner et al., 2004; Kam & Estes, 2016). However, little work has informed the mechanisms that give rise to this prejudice. We test a hypothesis focused on the smoke-detector principle: specific appearance-based prejudices (and related discriminatory behaviors) at least partially emerge from the tendency to make false-positive errors when estimating the presence of infectious disease. In signal detection theory, the tendency to make false positive errors can be quantified as the decision criterion (Stanislaw & Todorov, 1999), and a stronger tendency for false positives translates to lower values for the decision criterion (by convention this is called a more liberal criterion). Hence, specific appearance-based prejudice should be negatively associated with the decision criterion when estimating the presence of infectious disease. In other words, more prejudice is associated with a more liberal criterion, less prejudice is associated with a more conservative criterion.[2] While this hypothesis is implicit in much work on the behavioral

[2] Note that this is not the only hypothesis about pathogen avoidance and prejudice that could be formulated based on error management theory. Another hypothesis is that specific appearance-based prejudices are associated with tendencies to infer the presence of infectious disease based on a *broad range* of cues that superficially resemble cues of infectious disease. There is evidence consistent with this hypothesis (Oaten et al., 2011; Ryan et al., 2012; Tapp et al., 2020). We do not

immune system and prejudice (Aarøe et al., 2017; Faulkner et al., 2004; LoBue et al., 2022; Lund & Boggero, 2014; Lund & Miller, 2014; Miller & Maner, 2012; Park et al., 2003, 2007; Petersen, 2017; Ryan et al., 2012; Schaller, 2011, 2015; Tapp et al., 2020), direct tests of it are lacking.

The lack of such a direct test might seem inconsequential given the volume of related work linking the behavioral immune system to prejudice. However, existing work contains at least four important limitations. First, some studies that were interpreted as supportive rely on effects of motivations (to avoid pathogens) on beliefs about the degree to which a feature is associated with infectious disease (e.g., the degree to which obesity is associated with infectious disease) (Duncan & Schaller, 2009; Lund & Boggero, 2014; Miller & Maner, 2012; Park et al., 2003, 2007). These studies analyzed variation in pathogen avoidance motivations, both as measured (e.g., individual differences in germ aversion) and manipulated (e.g., experimentally manipulated the salience of infectious disease). Of course, individual differences in pathogen avoidance motivations might be associated with differences in beliefs that a particular group is associated with infectious disease. However, we think there is currently no good explanation for why such beliefs would be influenced by experimental manipulations of pathogen avoidance motivations. For example, Park et al. (2007, Study 2) manipulated disease salience to increase motivations to avoid infection and reported that “obese people were implicitly associated with disease-relevant concepts, and this association was especially strong following experimentally induced pathogen salience” (p. 413). However, such causal influence of motivations on beliefs seems inconsistent with the principle that beliefs (i.e., representations and associations between concepts) should be accurate rather than biased, because acting on the basis of inaccurate beliefs may be costly (Pinker, 2011; Van Leeuwen et al., 2023). If goal activation changes some beliefs and makes them inaccurate, then this increases the risk that subsequent decisions that draw on these beliefs are based on inaccurate information which could reduce successful goal pursuit.

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test this hypothesis in the current study. Further research could attempt to test this hypothesis with signal detection methods.

Therefore, beliefs should in general not be influenced by currently active goals. Applied to pathogen avoidance and obesity, this suggests that the association between obesity and infectious disease should not depend on moment-to-moment variations in motivation to avoid infection. Instead, an observer that is momentarily more motivated to avoid infection should adjust their decision criterion (i.e., requiring less evidence to act as if someone is infectious, for example by avoiding individuals who are only slightly overweight, rather than adjusting their belief about the relation between obesity and infectiousness). While it is possible that this is a case where changes in motivations have causal effects on beliefs (rather than having an effect on the decision criterion), this theoretical problem is currently unresolved.

Second, some of the supporting studies were conducted more than a decade ago and, as was standard at the time, were underpowered and not pre-registered (Duncan & Schaller, 2009; Miller & Maner, 2012; Park et al., 2003, 2007). Underpowered and not pre-registered studies may have a larger probability of Type 1 error (i.e., falsely rejecting the null hypothesis) due to the combination of small sample sizes possibly yielding highly variable estimates of effect size and the absence of preregistration allowing for flexibility in the analysis (i.e., researcher degrees of freedom). In contrast, several recent preregistered studies showed mixed or no support for relations between pathogen avoidance and prejudice toward sexual minorities (Inbar et al., 2016), minimal outgroups (Makhanova et al., 2022), and ethnic outgroups (Fan et al., 2022).

Third, some studies that were interpreted as supportive of the link between the smoke detector principle and prejudice used measures of implicit attitudes (Duncan & Schaller, 2009; Lund & Miller, 2014; Park et al., 2003, 2007), which have been criticized for low reliability and validity (Clayton et al., 2023; Forscher et al., 2019; Oswald et al., 2015). Unreliable measurement might have resulted in inaccurate estimates of the effects or associations, while invalid measurement might have resulted in estimating a different effect or association than was intended.

Fourth, few studies testing the relation between pathogen avoidance and prejudice have used signal detection methods and those that have used signal detection measures did not test the hypothesis that a liberal decision criterion is associated with more prejudice (Arshamian et al., 2021; Axelsson et al., 2018; Miller & Maner, 2012; Tskhay et al., 2016). In particular, Miller and Maner (2012) reported four studies showing that both self-reported vulnerability to disease and experimental manipulations of disease salience resulted in a bias to overperceive disease cues (i.e., a stronger tendency to perceive people as if they belonged to a social category associated with infectious disease, such as obese people). These studies involved categorization tasks (e.g., categorizing individuals on pictures as “fat” or “thin”) and memory tasks (e.g., indicating if they had or had not seen each photos before) for which signal detection measures were estimated. The studies did not ask participants to judge if target individuals were contagious and did not involve measures of prejudice.

Tskhay et al. (2016) reported four studies in which they showed participants photos of individuals with and without sexually transmitted diseases. Based on the photos alone, participants could detect if the individuals in the photos were ill or healthy with an accuracy above chance level. Axelsson et al. (2018) asked observers to look at photos of people recruited in Sweden and indicate whether the person in the photo is sick or healthy. The photos showed the faces of white young adults who appeared healthy or sick (due to receiving an injection of a bacterial endotoxin, see section 2.1 for further details). Signal detection analysis showed sickness detection above chance level (ROC curve area = 0.62). The study reported analyses aimed at identifying the cues that people used to detect sickness (e.g., pale lips), but did not include measures of prejudice. Arshaminian et al. (2021) used a subset of the stimuli used by Axelsson et al. (2018) and had the photos of Swedish individuals rated by observers from Sweden, Thailand, Mexico, and three hunter-gatherer communities: the Manic and Jahai of the Malay peninsula and the Seri from Mexico. Results showed that participants from all populations could detect sickness above chance levels in the Swedish models and that there was no ingroup advantage (i.e., Swedes did not perform better at detecting sickness than participants from non-Western populations).

Furthermore, these studies reported mixed findings regarding the general question of whether pathogen detection is biased towards false alarms. Both Tskhay et al. (2016) and Axelsson et al. (2018) found a bias toward misses: participants were more likely to categorize the target individuals as healthy than sick. Arshamian et al. (2021) found a bias towards false alarms for two of the six samples (i.e., Seri and Thai observers) but no evidence of bias for four of the six samples (for Swedish, Mexica, Jahai, and Manic observers).

1.4. Current study

To test the hypothesis that a liberal decision criterion is associated with prejudice toward particular social groups/categories, we will conduct a cross-sectional study that includes measures of both variables.

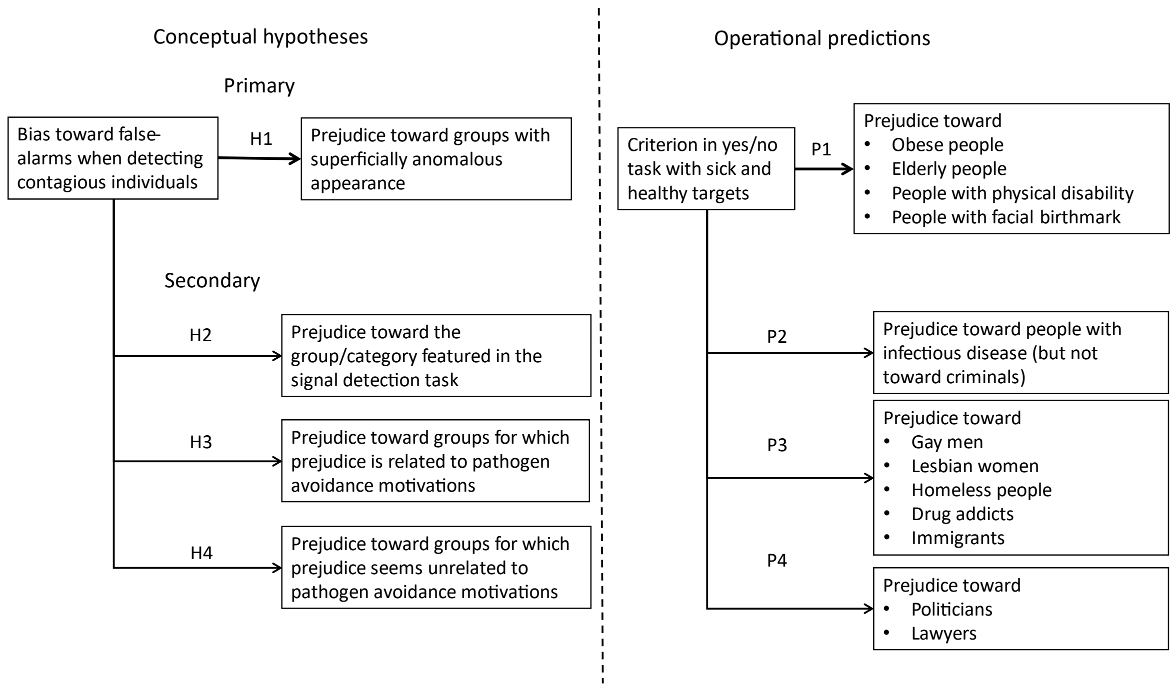
Conceptually, this hypothesis pertains to variation in the decision criterion when estimating the presence of infectious disease. Signal detection theory includes standard procedures (signal detection tasks) for measuring the decision criterion that an observer relies on. Such tasks require stimuli with and without a signal (i.e., with and without features or cues from which the observer could detect the presence of infectious disease). Existing work has relied on different methods to manipulate the presence of pathogen cues, sometimes using visual cues associated with infectious disease (Curtis et al., 2004; Fan et al., 2022; Petersen, 2017). Prior work has developed a model of contagiousness based on sickness induced by a bacterial-type inflammatory response (Arshamian et al., 2021; Axelsson et al., 2018; Lasselin et al., 2017). The stimuli developed in that work show facial photographs of individuals who show signs of infectious disease (i.e., with an acute inflammatory response) or not (i.e., without an acute inflammatory response). Thus, while these stimuli do not show individuals who are actually contagious, they show ecologically valid cues of symptomatic infectious disease. In the current study we include these stimuli in a signal detection task that asks participants to judge if the target person is contagious or not. Based on participants' responses we will estimate for each participant a decision criterion for detecting infectious disease.

Infectious disease poses a hazard and has a negative connotation. Therefore, it is possible that estimates based on the signal detection task described above reflect more general tendencies to see threats in others. We will thus include a second signal detection task in which participants are asked to evaluate if the person in the picture is a criminal (i.e., criminals pose another kind of risk, unrelated to infectious disease). In this task we will use pictures of men, some of whom are convicted criminals and some of whom are not (Valla et al., 2011).

Subsequently, we will measure prejudice toward multiple relevant social groups/categories. To test our primary hypothesis, we will measure prejudice toward four groups/categories that have been explicitly mentioned in theoretical work that invoked the smoke-detector principle (people with obesity, elderly people, people with physical disabilities, people with facial disfigurement). In addition, we will test three secondary hypotheses about the extent to which the relation between bias to detect pathogens and prejudice extends to other groups. We anticipate that interpretation of the findings for the primary hypothesis—and further theoretical development—will be aided by information about the specificity or generality of the relation between signal detection measures and prejudice. Therefore, we will include measures of prejudice for three other kinds of social groups/categories that seem relevant in this context. First, it is possible that the relation between bias toward false alarms and prejudice is very specific and is only observed when prejudice is measured for the same group that featured in the signal detection task. That is, bias toward false alarms when detecting infectious disease might relate to negative attitudes toward people with infectious disease (see Figure 1, H2). Second, because the primary hypothesis pertains to groups with an anomalous appearance, a key question is whether similar relations are observed for groups not characterized by anomalous appearance. Various groups without anomalous appearance are targets of prejudice or antipathy, some more associated with disease and/or pathogen disgust elicitors (e.g., gay men) and some less associated with disease and/or pathogen disgust elicitors (e.g., politicians). Therefore we include measures for groups for which prejudice is reliably associated with pathogen avoidance motivations (see Figure 1, H3) as well as groups for which the negative attitude seems driven by an association with dishonesty rather than infectious disease (see Figure 1, H4). We will test these hypotheses by estimating the relation between prejudice and the decision criterion for infectious disease.

Figure 1: Overview of hypotheses and operationalizations.

Caption: H1 is the primary hypothesis. H2, H3, and H4 are secondary hypotheses. H2 is that a bias to detect a negative feature is associated with prejudice to the group with that specific feature. H3 is that the decision criterion is related to prejudice for groups for which prejudice is putatively associated with pathogen avoidance motivations. H4 is that the decision criterion is related to prejudice for groups that are stigmatized for other reasons than pathogen avoidance. P1-P4 are the related operational predictions.



2. Method

2.1. Stimuli

Estimating individual differences in the decision criterion requires that there are individual differences in the hit rate and false-alarm rate for the signal detection task. In other words, the task requires ambiguous stimuli. There are multiple ways to make stimuli ambiguous: stimuli can be degraded (e.g., by adding noise) or presented very quickly, but doing so could reduce their ecological validity. We will use ecologically valid stimuli: pictures of human faces with or without sickness cues that are somewhat difficult (but not impossible) to detect for typical human observers.

We will use a subset of pictures used in previous research (Arshamian et al., 2021; Axelsson et al., 2018). Pictures were obtained from otherwise healthy participants who received an intravenous injection of a bacterial endotoxin (lipopolysaccharide, at a dose of 2.0 ng/kg body weight). The preregistered study (ClinicalTrials.gov identifier: NCT02529592) was conducted in 2015 and approved by the regional ethical review board in Stockholm, Sweden (2015/1415-32) (Axelsson et al., 2018; Lasselin et al., 2017). Participants were contacted again in 2022 to obtain their authorization to share their stimuli with researchers outside of the research group (ethics authorization: 2021-01405). The injection of lipopolysaccharide in healthy participants led to the acute activation of inflammatory processes and the development of sickness symptoms, mimicking a bacterial infection, for a few hours (Lasselin et al., 2020; Suffredini & Noveck, 2014). Twenty-two participants participated in two sessions in a counterbalanced order, separated by 3-4 weeks. They received an intravenous injection of lipopolysaccharide on one session, and an injection of saline (placebo) on the other session. Pictures were taken about 2h post-injection, the timepoint at which symptoms are most apparent.

Pictures used in this study were selected based on: (1) the quality of the photos in each condition (e.g. no large differences in facial hair or hairdo; 6 participants excluded); (2) authorization to share the photos to researchers outside of the research group (2 additional participants excluded). The final stimulus set included two photos (one in the sickness condition, one in the control condition) of each of 14 individuals (mean age = 21.9 *SD* = 2.4; 5 women, 9 men). All target individuals apparently had white skin. Previous research that used a subset of 32 photos from 16 individuals showed that these stimuli are ambiguous for typical human observers (Axelsson et al., 2018): the sensitivity to correctly identify sick individuals from these photos was 52% and for 13 out of 16 targets the raters were on average better than chance at detecting sickness. In addition, in a previous study (Tognetti et al., 2023) that used similar stimuli in a signal detection task for sickness with participants recruited from the same platform as the current study (Prolific), the decision criterion varied from about -1 to +2.

2.2. Signal detection task for sickness

We will use a yes/no task in which participants are shown pictures of human faces with or without sickness. We explain to participants that their task is to look at a series of photographs of individuals and identify individuals who are ill and potentially contagious. (The instructions clarify that participants should be vigilant for illness due to contagious disease, not non-infectious disease.) Each participant will be shown 14 pictures, one of each target person. For each participant, 7 pictures show a sick person and 7 pictures show a healthy person. A participant never sees the same target individual presented as both sick and healthy. We will prepare two sets of 14 pictures to counterbalance whether participants are presented the healthy or sick version of a particular target. We will construct these sets so that each participant is presented with both easy and difficult sick targets.

For each picture, participants have to decide if the person in the picture is ill and therefore potentially contagious: “Does this person have a contagious disease?”, with answer options *yes (sick)* and *no (healthy)*. From this yes/no task we will compute the decision criterion c with the standard formula (Arshamian et al., 2021; Stanislaw & Todorov, 1999): $c = \frac{\Phi^{-1}(H)+\Phi^{-1}(F)}{2}$. In this formula, Φ^{-1} (inverse phi) refers to the conversion of probabilities into z scores, H stands for the hit rate (= number of hits divided by the number of signal trials), and F stands for the false-alarm rate (= number of false alarms divided by the number of noise trials). Following standard procedures, hit rates and false alarm rates of 1 and 0 will be adjusted to 1-1/(2N) and 1/(2N), respectively, where N is the number of signal or noise trials (Stanislaw & Todorov, 1999). In short, for each participant we will compute a value $C_{INFECTED}$ for which higher values indicate a more conservative criterion (and lower values a more liberal criterion) when detecting contagious disease.

2.3. Signal detection task for criminality

The signal detection task for criminality will use facial photos of criminals and non-criminals. These pictures were selected from a set of 32 (Valla et al., 2011) that includes 16 photos of criminals and 16 controls (non-criminals). The photos show white US males without facial scars, tattoos or markings, and with little or no facial hair. The criminals were convicted of arson, assault, drug dealing, or rape. Previous research reported that human observers could detect criminals from these photos (d' = 0.5, hit rate = 72%, false alarm rate = 53%) (Valla et al., 2011). Valla et al. (2011) reported that on average, the rapists were rated as least likely to be criminals, while drug dealers were rated most likely to be criminals, with arsonists and assailants rated in between. For the current study, we selected 14 pictures (7 criminals, 7 non-criminals) so that both signal detection tasks would have the same number of trials. For the pictures of criminals we selected 4 assailants (target numbers 4, 24, 27, 28) and 3 arsonists (target numbers 5, 16, 20). We did not include pictures of rapists as these could be perceived differently by men and women. We selected 7 pictures of non-criminals that match the criminals in terms of hair color and eye color (target numbers 2, 7, 9, 13, 14, 17, 22).

For each picture, participants will decide if the person is a criminal: participants were asked “Is this person a criminal?”, with answer options *yes (criminal)* and *no (not a criminal)*. The order of the two signal detection tasks will be counterbalanced across participants. The decision criterion is computed using the same formula. In short, for each participant we will compute a value $C_{CRIMINAL}$ for which higher values indicate a more conservative criterion (and lower values a more liberal criterion) when detecting criminality.

2.4. Measures of prejudice

Prejudice is often defined as a negative attitude towards a particular group or category (Correll et al., 2010; Stangor, 2016). However, there is no agreed-upon gold standard for measuring prejudice. Widely-used measures of prejudice include measures of emotional responses (Ramasubramanian, 2011; Talaska et al., 2008), social distance measures, which measure comfort with various forms of social contact (Bogardus, 1933; Parrillo & Donoghue, 2013), and measures of global evaluations, such as feeling thermometers (Correll et al., 2010) or evaluative semantic differential items (Bohner & Wänke, 2002). We will measure prejudice with five items that relate to both affective responses (i.e., feeling warm vs. cold, like vs. dislike, and degree of feeling disgusted towards the group) and comfort with social contact (two items based on standard social distance measures) (all rated on a 7-point scale, see supplementary materials for details). For each group, we will rescale the five items to a common range (0 to 1), for each individual we will average responses to the five items and assign them a score that indexes their prejudice (i.e., higher values indicate a more negative attitude).

We will measure prejudice toward twelve groups/categories that can be divided in four clusters (see Figure 1):

(1) Four social categories that have been explicitly mentioned in explanations of prejudice that relied on the smoke-detector principle (for item formulations, see supplementary materials): people with obesity (Park et al., 2007), elderly people (Duncan & Schaller, 2009), people with a physical disability (Park et al., 2003), and people with a facial disfigurement (Ryan et al., 2012). Estimating the relation between the decision criterion for contagious disease and prejudice for these groups informs the primary hypothesis that prejudice toward groups with anomalous appearance is due to the smoke detector principle (H1).

(2) Two social categories that were included in the signal detection tasks: i.e., people with an infectious disease and criminals. Estimating the relation between the decision criterion and prejudice for these groups informs whether the smoke detector principle holds for the social group for which the response bias was measured (H2).

(3) Five social categories for which prejudice is putatively motivated by pathogen avoidance, but not based on anomalous appearance. Relations between pathogen

avoidance motivations and prejudice have been observed for gay men and lesbian women (Kiss et al., 2020; van Leeuwen et al., 2022), homeless people (Clifford & Piston, 2017; Hodson & Costello, 2007), drug addicts (Hodson et al., 2013; Hodson & Costello, 2007), and immigrants (Aarøe et al., 2017; Faulkner et al., 2004). We will assess responses for the following groups: gay men, lesbian women, homeless people, drug addicts, and immigrants. While members of these social categories sometimes have an unusual appearance, the membership of the category is not determined based on physical appearance alone. In other words, an observer might feel disgust toward members of these categories, but not because their appearance is unusual, but rather because their behavior violates norms and/or evokes disgust. Estimating the relation between the decision criterion and prejudice for these groups informs whether the smoke detector principle contributes to prejudice toward social categories for which prejudice is related to pathogen avoidance motivations, but less associated with atypical appearance (H3).

(4) Two social categories that are common targets of prejudice in the population from which we recruit our participants—but which are not based on physical appearance and for which the prejudice seems not associated with infectious disease or pathogen avoidance motivations: i.e., politicians and lawyers. In the US, politicians and lawyers are associated with violations of cooperative norms, in particular dishonesty and unethical behavior (Gallup, 2023). Prior work found that the relation between pathogen disgust sensitivity and prejudice toward lawyers was not significant, while the relation for prejudice toward politicians was significant. However, given that this effect was relatively small, it seems to us more likely that this relationship is due to pathogen disgust sensitivity being correlated with moral disgust sensitivity, rather than prejudice toward politicians is due to people associating politicians with infectious disease (explicitly or implicitly). Estimating the relation between the decision criterion and prejudice for these groups informs if the smoke

detector principle extends to prejudice toward social categories that are stigmatized for reasons other than infectious disease (H4).

2.5. Additional variables

For sample descriptives, robustness checks (see below), and exploratory analysis, we will include items to measure participant's age, sex, self-reported membership of the groups for which prejudice is assessed, whether they currently live in the US, whether English is their native language, and their race/ethnicity. In addition, we asked participants to rate their feelings of sickness with one item, "I feel sick" (rated on a 7-point Likert scale from *Strongly disagree* to *Strongly agree*). Previous work showed that responses to this item were strongly correlated with a multi-item measure of sickness behavior (Andreasson et al., 2018).

For exploratory analysis, we will measure pathogen disgust sensitivity with seven items (e.g., "Stepping on dog poop" rated on a scale from *Not disgusting at all* [0] to *Extremely disgusting* [6]) from the Three-Domain Disgust Scale (Tybur et al., 2009).

Finally, to assess if participants completed the study attentively, we include an attention check. After the seventh item for pathogen disgust sensitivity, we include the item: "Please select the midpoint of the scale". Participants who provide any other answer fail the attention check and will be excluded from analysis.

2.6. Analysis Strategy

We will report descriptive statistics (minimum, maximum, mean, SD) for all variables and a correlation table. To test the hypotheses, we will estimate separate models for each of the thirteen target groups, and regress prejudice toward each group on an intercept, sex (contrast coded as female: -0.5, male: 0.5), and $C_{INFECTED}$. We will control for sex because existing work points to substantial sex differences in disgust sensitivity (Sparks et al., 2018) as well as prejudice (Ekehammar & Sidanius, 1982; van Leeuwen et al., 2022; Watts, 1996; Whitley, 1999). (This model assumes that the relation between $C_{INFECTED}$ and the outcome is similar for males and females. To verify this assumption we will estimate a model that includes the interaction between sex and $C_{INFECTED}$. When the interaction is significant we will proceed with slopes estimated for each sex separately.) Previous empirical and theoretical work does not point to a particular magnitude that the hypothesized relation should have. Hence, our strategy relies on null-hypothesis significance testing: Support for the hypothesis is indicated by a regression coefficient for $C_{INFECTED}$ that is negative and significant (i.e., $p < .05$). Because our hypothesis is directional, we will calculate one-sided *p*-values that test whether the regression coefficient is smaller than zero. Nevertheless, a negative non-zero (small) relation does not necessarily provide strong support for the hypothesis. We think strong support for the hypothesis is revealed by relations that are consistent, valid, and substantial. To evaluate this we will follow the analysis plan described below.

(1) To evaluate H1, we will estimate the regression coefficient for four targets: obese people, elderly people, people with physical disability, and people with facial birthmarks. Consistent support for the hypothesis would be provided by significant negative regression coefficients for all four targets.

(2) Participants might give positive ratings toward their own ingroup (e.g., participants with obesity reporting positive attitudes toward people with obesity). Therefore, the relation between $C_{INFECTED}$ and prejudice toward a particular group can be estimated without this group membership bias by excluding participants who belong to that group. Hence, we will estimate the regression coefficients for each target group while excluding participants who identify as belonging to that group. Confidence in H1 should be higher if the relation remains (or becomes) significant.

(3) To increase internal validity, we will check if the relation between $C_{INFECTED}$ and prejudice can be attributed to a plausible confound. The relation could be confounded with a general response bias toward negative stimuli. Therefore, we will test if the relation between prejudice and $C_{INFECTED}$ is significant when controlling for $C_{CRIMINAL}$ in an otherwise identical regression model. Confidence in H1 should be higher if the relation between $C_{INFECTED}$ and prejudice remains (or becomes) significant.

(4) To evaluate if the relations are of substantial magnitude, we will compare the regression coefficients for (i) $C_{INFECTED}$ and $C_{CRIMINAL}$, and (ii) $C_{INFECTED}$ and participant sex with Wald tests. If the regression coefficient of $C_{INFECTED}$ is larger than both, then this indicates that the relation is of substantial magnitude.

We will test H2, H3, and H4 using a similar approach. H2 is supported when $C_{INFECTED}$ predicts prejudice toward people with infectious disease but not criminals. H3 is supported when $C_{INFECTED}$ has a significant negative relation with prejudice toward the five targets (gay men, lesbian women, homeless people, drug addicts, and immigrants). H4 is supported when $C_{INFECTED}$ has a significant negative relation with prejudice toward lawyers and politicians.

Although we test H1 four times (once for each target group), we will not adjust our inferences for multiple comparisons. This is because we will not consider scenarios in which e.g. one out of the four coefficients is significant to constitute particularly strong evidence for the hypothesis. Rather, as indicated above, we will make a qualitative judgment on the consistency of the supporting evidence based on a continuum from weak (1/4 significant relations) to strong (4/4 significant relations).

Finally, we will conduct exploratory analyses: We will estimate relations between pathogen disgust sensitivity, signal detection parameters (response bias and sensitivity), and prejudice.

2.7. Participants

We estimated, via simulation (see supplementary material), that the model detailed above required a minimum of 1,400 participants for 90% power to detect negative associations at (one-sided) alpha 0.05, if the true correlation between $C_{INFECTED}$ and prejudice is $r = 0.1$. These simulations assumed three standard normal distributions (prejudice, standardized sex, criterion) where prejudice and $C_{INFECTED}$ correlated at $r = 0.1$, prejudice and sex at $r = 0.2$, and $C_{INFECTED}$ and sex at 0.1. Moreover, because we will exclude some participants from the analysis (see criteria below), we will oversample an additional 100 participants (total N = 1500) to ensure that power is retained even after exclusions.

Ideally, we recruit participants from a population in which there exists a substantial relation between pathogen avoidance motivations and prejudice. There is some evidence that the relation between pathogen avoidance motivations and prejudice is not specific to particular cultures (van Leeuwen et al., 2022). However, this evidence is specific to prejudice towards a narrow set of groups. Existing work has mostly sampled from US or Canadian populations. For these populations, research has reported relations between individual differences in pathogen avoidance motivations and prejudice toward people with obesity (Lieberman et al., 2012; Park et al., 2007), immigrants (Aarøe et al., 2017; Ji et al., 2019; Karinen et al., 2019), people with a physical disability (Park et al., 2003), gay men and lesbian women (Crawford et al., 2014; Kiss et al., 2020; Lai et al., 2014), homeless people (Clifford & Piston, 2017), and low-status groups (Hodson & Costello, 2007). Two studies with mixed US/UK samples found mixed evidence for a relation between pathogen avoidance motivations and prejudice towards the elderly (Nicol et al., 2021). We conclude that the relation between pathogen avoidance and prejudice is best supported for the US population. Therefore, we will recruit participants from the US with Prolific (www.prolific.com). Prolific is a widely used survey platform that enables recruiting large samples with good data quality (Demoulin et al., 2021; Fan et al., 2022; Jones et al., 2019).

We will exclude from the analysis participants who (1) fail the attention check, (2) are not native speakers of English, (3) do not live in the US, and (4) have missing responses on 5 or more trials on the detection task for contagious disease (i.e., to be included a participant must have responded to at least 10 of the 14 trials).

This research was approved by the Ethics Review Board of the institution of the first author. Participants will provide informed consent before participating and will receive debriefing information after completion of the study.

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