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The smoke-detector principle of pathogen avoidance: A test of how the behavioral immune system gives rise to prejudice

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ABSTRACT

Motivations to avoid infectious disease seem to influence prejudice toward some groups, including groups not explicitly associated with infectious disease. The standard explanation for this phenomenon is based on signal detection theory and proposes that some prejudices partially arise from pathogen detection mechanisms that are biased toward making false alarms (false positives) in order to minimize 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 tested 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. To test the hypothesis, we conducted a cross-sectional study using a large U.S. sample ($N = 1450$). Using signal detection theory methods, we assessed tendencies to make false alarms when identifying infection threats. We further assessed prejudice toward multiple relevant social groups/categories. Results showed weak evidence for the key hypothesis: for only one of four tested target groups were tendencies to make false alarms in sickness detection significantly associated with prejudice. However, this relation was not significant when controlling for a potential confound. These results cast doubt on the notion that individual differences in appearance-based prejudices arise from individual differences in tendencies to make false alarms in assessing pathogen threats.

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

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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 type of error (a false positive) is generally less costly than the former (a false negative) (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 fire is present, people are expected to frequently treat others 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.[2]

Multiple studies have argued that pathogen detection mechanisms categorize a broad array of atypical features (i.e., 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) provide the following explanation of how false-positive errors may give rise to prejudice:

> (B)ecause of the smoke-detector principle…(p)sychologically 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 targets whose appearance is not obviously anomalous, including ethnic outgroups, immigrants, and gay men (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), relations between pathogen avoidance and prejudice might further arise via social learning or social influence. First, people sometimes associate outgroups with infectious disease via 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; Karinen et al., 2019), 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, building on error management theory, Oaten et al. (2011) 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 not found 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 and threats that others pose to them and that this can lead to prejudice, stigma, and discrimination (Krems & Neuberg, 2022; Pirlott & Cook, 2018). This approach can account for some relations between pathogen avoidance and prejudice, such as negative attitudes toward individuals and groups (e.g., gay men) that are (correctly or incorrectly) explicitly associated 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 people respond to various anomalous appearances 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 logic 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

[2] 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.

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 toward 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. Here, 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 (or: less prejudice is associated with a more conservative criterion).[3] While this hypothesis is implicit in much work on the behavioral 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 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. Therefore, beliefs should in general not be influenced by currently active goals. Applied to pathogen avoidance and obesity, this reasoning 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 have a larger probability of Type 1 error (i.e., falsely rejecting the null hypothesis) due to the combination of small sample sizes yielding more 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 photo before) from 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

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

used to detect sickness (e.g., pale lips), but did not include measures of prejudice. Arshamian 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 toward 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 toward 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 conducted a cross-sectional study including 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 included these stimuli in a signal detection task in which participants judged whether the target is contagious or not. Based on these responses, we estimated a decision criterion for detecting infectious disease for each participant.

Infectious disease poses a hazard and has a negative connotation. Therefore, estimates based on the signal detection task described above might reflect more general tendencies to see threats in others. We thus included a second signal detection task in which participants evaluated whether the person in the picture is a criminal. In this task we used pictures of men, some of whom are convicted criminals and some of whom are not (Valla et al., 2011).

Subsequently, we measured prejudice toward multiple relevant social groups/categories. To test our primary hypothesis, we measured prejudice toward four groups/categories that have been explicitly mentioned in theoretical work invoking the smoke-detector principle (people with obesity, elderly people, people with physical disabilities, people with facial disfigurement). In addition, we tested three secondary hypotheses about the extent to which the relation between prejudice and bias to detect pathogens extends to other groups. We anticipated that the interpretation of findings relevant to the primary hypothesis—and further theoretical development—would be aided by information about the specificity or generality of the relation between signal detection measures and prejudice. Therefore, we included additional measures of prejudice toward three other kinds of social groups/categories that seem relevant in this context. First, the relation between bias toward false alarms and prejudice might be very specific and 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 Fig. 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 included measures for groups for which prejudice is reliably associated with pathogen avoidance motivations (see Fig. 1, H3) as well as groups for which the negative attitude seems driven by an association with dishonesty rather than infectious disease (see Fig. 1, H4). We tested these hypotheses by estimating the relation between prejudice and the decision criterion for infectious disease.

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 used 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 used 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 2 h 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.

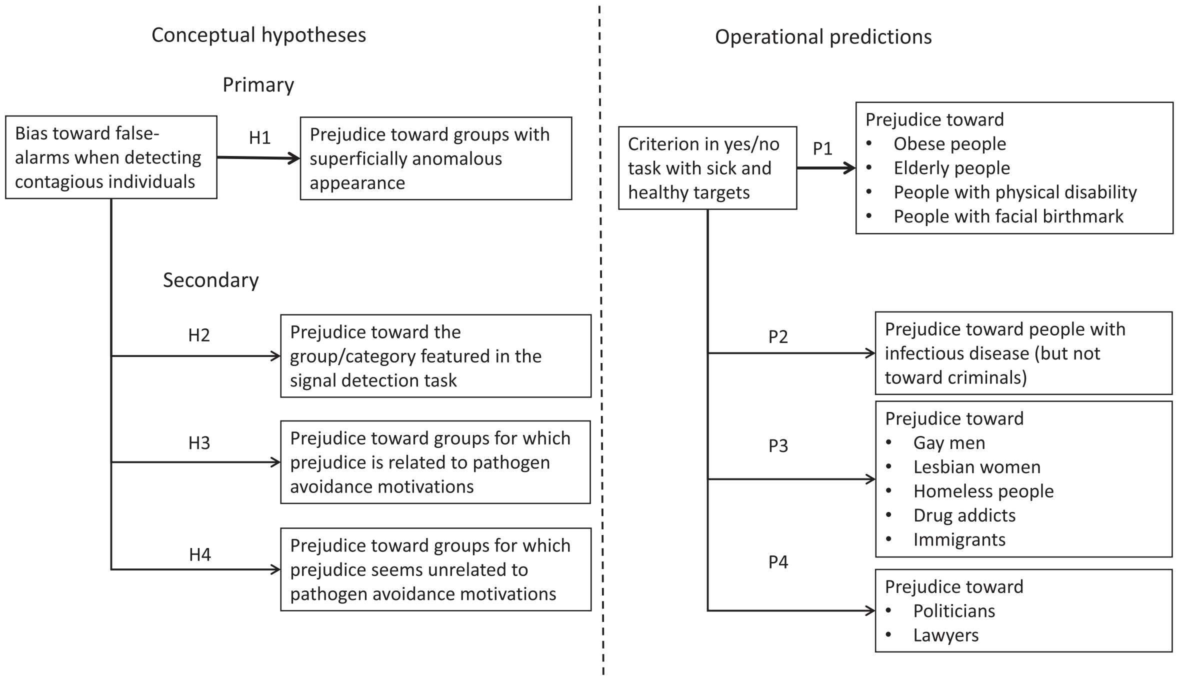

Fig. 1. Overview of hypotheses and operationalizations.
H1 is the primary hypothesis. H2, H3, and H4 are secondary hypotheses. H2 is that a bias to detect a negative feature is associated with prejudice to the group with that specific feature. H3 is that the decision criterion is related to prejudice 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.

2.2. *Signal detection task for sickness*

We used a yes/no task in which participants were shown pictures of human faces with or without sickness. We explained 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 was shown 14 pictures, one of each target person. For each participant, 7 pictures showed a sick person and 7 pictures showed a healthy person. A participant never saw the same target individual presented as both sick and healthy. We prepared two sets of 14 pictures to counterbalance whether participants saw the healthy or sick version of a particular target. We constructed these sets so that each participant was presented with both easy and difficult sick targets, which was determined based on the accuracy of ratings in previous work (Axelsson et al., 2018).

For each picture, participants decided if the person in the picture was 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 computed 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 were adjusted to 1–1/(2 N) and 1/(2 N), respectively, where N is the number of signal or noise trials (Stanislaw & Todorov, 1999). In short, for each participant, we computed 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 used 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 showed white U.S. 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 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 decided 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 was counterbalanced across participants. The decision criterion was computed using the same formula. In short, for each participant, we computed a value $C_{CRIMINAL}$ for which higher values indicated 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 toward 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 measured prejudice with five items related to both affective responses (i.e., feeling warm vs. cold, like vs. dislike, and degree of feeling disgusted toward 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 rescaled the five items to a common range (0 to 1); for each individual we averaged responses to the five items and assigned them a score that indexes their prejudice (i.e., higher values indicate a more negative attitude).

We measured prejudice toward thirteen groups/categories, which we a priori divided into four clusters (see Fig. 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 (i.e., people with tuberculosis) 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 assessed 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, 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: politicians and lawyers. In the U.S., 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 included items to measure participants' age, sex, whether they currently live in the U.S., whether English is their native language, and their race/ethnicity. We assessed self-reported membership in the groups for which prejudice was assessed, by asking participants to indicate for each of the thirteen groups whether they consider themselves to be part of the group. 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 measured 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). Participants' average score on the scale was also rescaled to range from 0 to 1.

Finally, to assess if participants completed the study attentively, we included an attention check. After the seventh item for pathogen disgust sensitivity, we included the item: "Please select the midpoint of the scale". Participants who provided any other answer failed the attention check and were excluded from analyses.

2.6. Analysis strategy

We report descriptive statistics in Table 1 and correlations in Table 2. To test the registered hypotheses described above, we estimated separate models for each of the thirteen target groups and regressed prejudice toward each group on an intercept, participant sex (contrast coded as female: −0.5, male: 0.5), and $C_{INFECTED}$. We controlled for participant 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 also estimated models that included the interaction between sex and $C_{INFECTED}$. For any models with significant interactions, we report slopes 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 calculated one-sided *p*-values that test

Table 1
Descriptive statistics.

	M	*SD*	Min	Max
$C_{INFECTED}$	0.3	0.6	−1.5	1.5
$C_{CRIMINAL}$	0.1	0.6	−1.5	1.5
Prejudice obese	0.4	0.2	0.0	1.0
Prejudice elderly	0.1	0.2	0.0	0.8
Prejudice missing limb	0.2	0.2	0.0	1.0
Prejudice birthmark	0.2	0.2	0.0	1.0
Disgust sensitivity	0.7	0.2	0.0	1.0
Age	41.8	13.4	18.0	83.0

Note: All variables escept age were rescaled to range from 0 to 1.

Table 2
Correlation matrix of key variables.

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
1. $C_{INFECTED}$	1	.	.	.	.	.	.	.	.	.
2. $C_{CRIMINAL}$	0.47***	1	.	.	.	.	.	.	.	.
3. d' (sick)	−0.11***	−0.07**	1	.	.	.	.	.	.	.
4. d' (criminal)	−0.05*	−0.09***	0.00	1	.	.	.	.	.	.
5. Obese	0.01	−0.06*	−0.03	0.04	1	.	.	.	.	.
6. Elderly	−0.00	−0.03	−0.07**	−0.08**	0.35***	1	.	.	.	.
7. Missing limbs	−0.03	−0.04	−0.06*	0.00	0.49***	0.58***	1	.	.	.
8. Birthmark	−0.05^{+}	−0.04	−0.05^{+}	−0.03	0.53***	0.50***	0.70***	1	.	.
9. Disgust sensitivity	−0.10***	−0.07**	−0.03	0.08**	0.06*	−0.15***	−0.06*	0.00	1	.
10. Age	0.08**	0.03	−0.09***	−0.02	−0.06*	−0.19***	−0.12***	−0.05*	0.05^{+}	1

Note: Variables 5–8 show prejudice scores toward different targets. Higher scores on $C_{INFECTED}$ and $C_{CRIMINAL}$ correspond to a higher likelihood of identifying individuals as sick and as criminals. Higher scores on d' (sick) and d' (criminal) correspond to higher accuracy in identifying sick (vs. healthy) individuals and criminals (vs. non-criminals).

$^{+}$ $0.1 \geq p > .05$.

* $0.05 \geq p > .01$.

** $0.01 \geq p > .001$.

*** $0.001 > p$.

whether the regression coefficient is less than zero. Nevertheless, a negative non-zero (small) relation does not necessarily provide strong support for the hypothesis. Strong support for the hypothesis is revealed by relations that are consistent, valid, and substantial. To evaluate the strength of support we followed the analysis plan described below.

(1) To evaluate H1, we estimated 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 estimated 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 checked 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 tested whether 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 compared the regression coefficients for (i) $C_{INFECTED}$ and $C_{CRIMINAL}$, and (ii) $C_{INFECTED}$ and participant sex with Wald tests. A regression coefficient of $C_{INFECTED}$ larger than both indicates that the relation is of substantial magnitude.

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

Although we tested H1 four times (once for each target group), we did not adjust for multiple comparisons. We chose this approach because we did not consider scenarios in which, for example, one out of the four coefficients is significant to constitute particularly strong evidence for the hypothesis. Rather, as indicated above, we made 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 conducted exploratory analyses estimating 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 1400 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 recruited an additional 100 participants (total $N = 1501$) to ensure that power was retained after exclusions.

We wanted to 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 toward a narrow set of groups. Existing work has mostly sampled from U.S. 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 U.S./UK samples found mixed evidence for a relation between pathogen avoidance motivations and prejudice toward the elderly (Nicol et al., 2021). We conclude that the relation between pathogen avoidance and prejudice is best supported for the U.S. population. Therefore, we recruited participants from the U.S. via Prolific (www.prolific.com), which 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). Participants were rewarded according to Prolific guidelines and were paid 1.70 GBP.

We excluded from the analysis participants who (1) failed the attention check, (2) reported that they were not native speakers of English, (3) reported not living in the U.S., or (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 Tilburg University (TSB_RP1371). Participants provided informed consent before participating and received debriefing information after completion of the study. The data and analysis code are available via https://osf.io/386dc/.

3. Results

3.1. Descriptive statistics

After excluding 51 individuals who did not satisfy the inclusion criteria (28 failed the attention check; 15 reported a non-English first language; 2 were not based in the US; 0 had more than 5 missing values in the sickness detection task) and who reported a sex other than male or female ($n = 9$),[4] the final sample consisted of 1450 individuals (690 men, 760 woman). All analyses were conducted in R. We used the *marginaleffects* package for testing slopes and their contrasts and *tidyverse* for data cleaning and visualization (Arel-Bundock et al., 2024; R Core Team, 2024; Wickham et al., 2019).

Summary statistics and correlations between key variables are shown in Tables 1 and 2, respectively. The decision criteria for the two detection tasks were moderately positively correlated. Moderate positive correlations were also observed between prejudice measures toward the four key target groups.

We then considered the quality of our measures. First, we calculated Cronbach's alphas for all measurement scales (all exceeded 0.77, see Table S4). Second, we calculated for how many individuals the hit rates and false alarm rates had to be adjusted (see Section 2.2). These numbers are shown in Table S5. For the sickness detection task, false alarm rates were adjusted for 14 % of participants (13 % with false alarm rate of 0, 1 % with a false alarm rate of 1) and hit rates were adjusted for 9 % of participants (7 % with hit rate of 0, 2 % with hit rate of 1). For the criminality detection task, 12 % had false alarm rate of 0 and 2 % a false alarm rate of 1; 6 % had a hit rate of 0 and 7 % a hit rate of 1. This shows that for most participants hit rates and false alarm rates did not need to be corrected.

Third, we examined the task performance and signal detection parameters in detail for both signal detection tasks (see descriptive statistics in Table S6). We examined the item functioning of the stimuli in both detection tasks by calculating the percentage of correct judgments for each stimulus. In short, for the stimuli in the sickness detection task, the percentage of correct responses ranged from about 20 % to about 85 %, and for criminality detection from about 45 % to 75 % (see Fig. S3). We then compared the sickness detection hit rates and false alarm rates for each stimulus in our study to those in a prior study using the same stimuli (Axelsson et al., 2018); by and large these were very similar (see Fig. S4).

3.2. Hypothesis 1

We then tested our main hypothesis, H1, that people with a liberal infectious disease decision criterion—a tendency to respond "sick"—would report greater prejudice toward people with obesity, elderly people, people with a physical disability, and people with a facial disfigurement. To test H1, we regressed prejudice scores for these groups (in separate models) on $C_{INFECTED}$. We included sex (coded as woman: −0.5, man: 0.5) as a covariate to reduce residual variance. We visualize all bivariate relations in Fig. 2 and report the key regression parameters in the first four rows of Fig. 3 (Test 1, see also Table S7). We also tested models that included the interaction effect between sex and $C_{INFECTED}$. Because the interaction was not significant in any of the four models, we only report the common coefficient for these groups. Of the four key target groups, $C_{INFECTED}$ had a statistically significant negative relation only with prejudice toward individuals with a facial disfigurement (Fig. 3, Test 1).

We next examined the regression coefficients in models that excluded participants who identified with the target group (Test 2); adjusted for $C_{CRIMINAL}$ (Test 3); and compared $C_{INFECTED}$ with $C_{CRIMINAL}$ and the sex coefficient (Test 4). Coefficients from models that excluded participants who identified with the target group are shown in Fig. 3 (Test 2). For details, see Table S8. Results did not differ from those of the main analysis.

Results adjusting for $C_{CRIMINAL}$ (Fig. 3, Test 3) were qualitatively similar, with one key difference: the relationship between $C_{INFECTED}$ and prejudice toward individuals with a facial disfigurement was no longer statistically significant. For details, see Table S9.

Finally, we tested whether the relations $C_{INFECTED}$ and prejudice were stronger than those between $C_{CRIMINAL}$ and prejudice and between participant sex and prejudice (Fig. 3, Test 4; for details, see Table S10) Across the four target groups, $C_{INFECTED}$ was not a stronger predictor of prejudice than either $C_{CRIMINAL}$ or participant sex (men generally reported greater prejudice). Overall, then, across the four target groups and four analyses, we found at best weak evidence for hypothesis 1.

3.3. Hypotheses 2, 3, and 4

We next turned to whether biases toward seeing infection and criminal threats relates to prejudice toward people with tuberculosis and toward prisoners, respectively (H2; see also Tables S7 to S10). $C_{INFECTED}$ related to prejudice toward prisoners (in analyses 1 and 2) but not toward individuals with tuberculosis. The coefficient for $C_{INFECTED}$ was not significantly different from those of $C_{CRIMINAL}$ or participant sex (Table S10). We therefore found no support for hypothesis 2.

We then tested whether biases toward seeing infection relate to prejudice toward groups putatively associated with pathogens, but for reasons apart from anomalous appearance (H3). $C_{INFECTED}$ was associated with prejudice toward gay men and lesbian women across tests 1 to 3 (Fig. 3). For one target group, the relation was moderated by participant sex; $C_{INFECTED}$ related to prejudice toward immigrants for women but not for men. We did not detect a relation between $C_{INFECTED}$ and prejudice toward homeless individuals or drug addicts. We therefore found partial support for H3.

Finally, we tested whether biases to see infection relate to prejudice toward target groups presumably not associated with pathogen threats (H4). We did not detect a relation between $C_{INFECTED}$ and prejudice toward either politicians or lawyers. Instead, across tests, the relationship between $C_{INFECTED}$ and prejudice toward politicians was positive and significant, meaning tendencies to see infection in ambiguous faces related to less prejudice toward these groups.

3.4. Exploratory analysis

We examined relations between pathogen disgust sensitivity, response bias and sensitivity in the sickness detection task, and prejudice. We report these results in Supplementary materials Table S3. First, we regressed pathogen disgust sensitivity on $C_{INFECTED}$, d-prime, age, and participant sex.[5] Consistent with the literature, women scored higher on pathogen disgust sensitivity than men ($d = 0.34$). More

[4] The exclusion of individuals who reported a sex other than male or female was not explicitly mentioned in the Stage 1 report. We excluded these individuals from analysis because the test of H1 controls for sex.

[5] We tested for a sex difference in pathogen disgust sensitivity. A Welch Two Sample *t*-test of the difference in pathogen disgust sensitivity by sex suggests that the difference is in the typical direction, significant, and small (mean women = 0.72, mean men = 0.67, difference = 0.06, 95 % CI [0.04, 0.07], $t(1418.86) = 6.34$, $p < .001$, Cohen's $d = 0.34$).

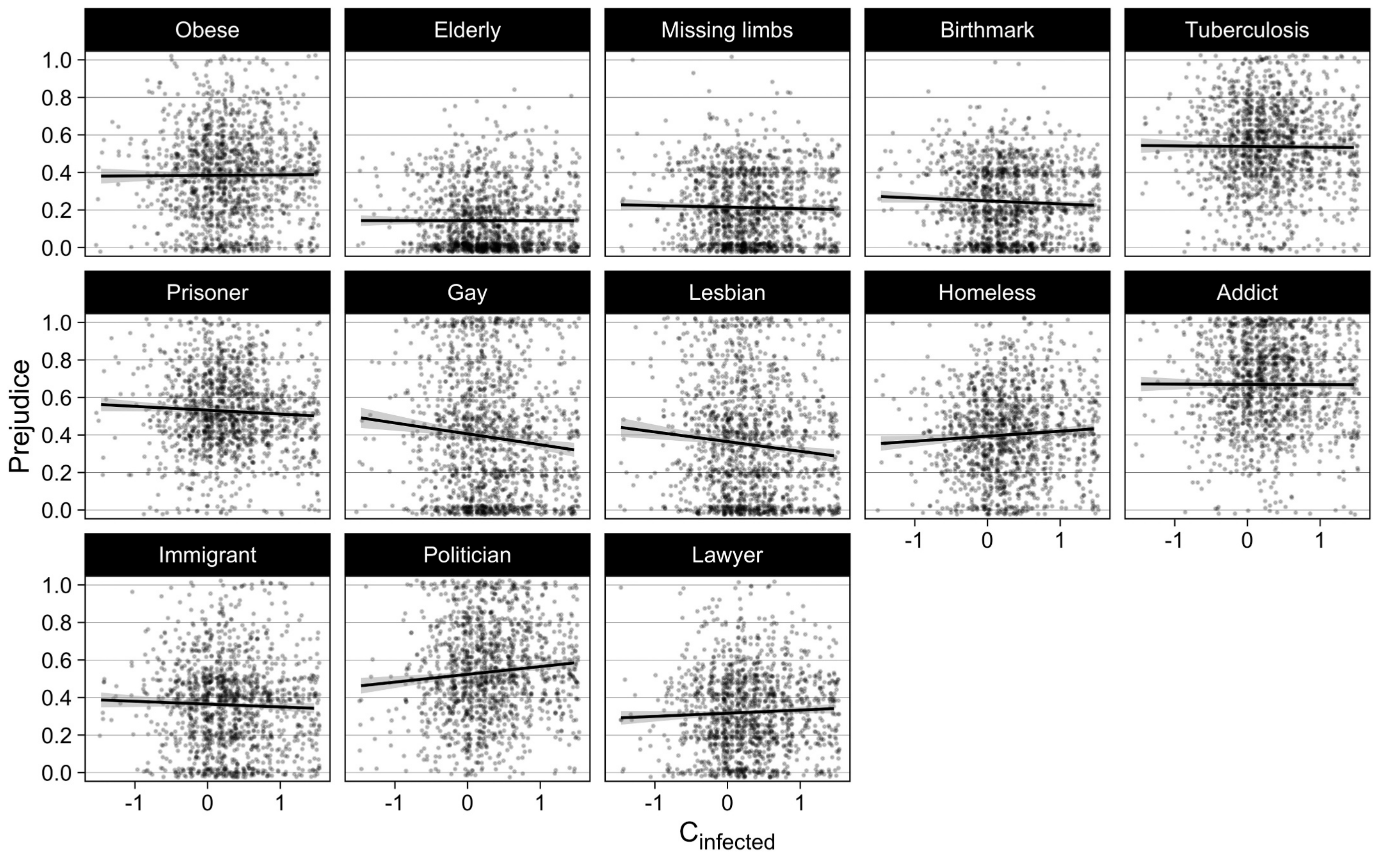

Fig. 2. Scatterplots and regression lines (with 95 % CIs) for each prejudice scale on signal detection criteria in the contagion detection task. Negative values of $C_{INFECTED}$ indicate a “liberal” response bias toward answering “sick”, and positive values indicate a “conservative” bias toward answering “healthy”. Points are jittered to reduce overplotting.

pertinent to the primary hypotheses tested here, pathogen disgust sensitivity was negatively associated with $C_{INFECTED}$, but not with d-prime. In other words, stronger pathogen disgust sensitivity was associated with a tendency to make more false alarms in the sickness detection task, but not with increased sensitivity in the sickness detection task. Second, in separate models we regressed prejudice toward each target group on pathogen disgust sensitivity, age, and sex. In short, pathogen disgust sensitivity was associated with increased prejudice toward 8 out of 13 groups: obese people, people with tuberculosis, people who had been to prison, gay men, lesbian women, homeless people, addicts, and immigrants. It was associated with less prejudice toward elderly people and lawyers. For the remaining 3 groups (people with a physical disability, people with a facial birthmark, and politicians), the relation was not significant.

We then considered an alternative analytic approach for testing the overall hypothesis that a liberal infectious disease decision criterion is associated with prejudice toward the four key groups (H1). Above, we tested this idea separately for each of the four groups. Here, we model the relationship between $C_{INFECTED}$ and prejudice across the four groups in one multilevel model to accomplish three goals: (A) Estimate an average relation between $C_{INFECTED}$ and prejudice across the groups; (B) avoid overfitting target-group-specific relations using partial pooling; and (C) evaluate evidence for the null hypothesis that the average relationship between $C_{INFECTED}$ and prejudice is zero using a bayes factor approximated with the Savage-Dickey density ratio (Wagenmakers et al., 2010).

We modeled the *z*-scored prejudice rating P for the *i*th participant and *j*th target group with a standard multilevel model specified as

$$
\begin{aligned}
\mathrm{P}_{ij} &\sim \mathrm{Normal}\left(\eta_{ij}, \sigma^2\right), \\
\eta_{ij} &= \beta_0 + \gamma_{0j} + \delta_{0i} + \beta_1 \mathrm{S}_{ij} + \left(\beta_2 + \gamma_{1j}\right)\mathrm{C}_{ij}, \\
\begin{bmatrix} \gamma_0 \\ \gamma_1 \end{bmatrix} &\sim \mathrm{MVN}\left(\begin{bmatrix} 0 \\ 0 \end{bmatrix}, \begin{pmatrix} \tau_0 & \\ \rho & \tau_1 \end{pmatrix}\right), \\
\delta_0 &\sim \mathrm{Normal}(0, \tau_\delta), \\
\tau &\sim \mathrm{t}^{+}(7, 0, 0.33), \\
\beta_2 &\sim \mathrm{Normal}(0, \phi).
\end{aligned}
$$

Above, we denote prejudice as P, sex (woman: −0.5, man: 0.5) as S, and $C_{INFECTED}$ as C. β_2 and γ_1 are the population-level and target-group-specific deviations in regression slopes of prejudice on $C_{infected}$, respectively. Critically, because we could not determine an exact prediction for the average effect size based on previous work or theory, we estimated the model across a range of priors for the standard deviation of the population-level relationship $\phi \in \{0.1, 0.25, 0.5, 0.75, 1\}$. For the other model parameters, we used the brms’ package’s default priors (Bürkner, 2017, 2018).

First, we show the estimated relation between $C_{INFECTED}$ and prejudice toward the average target group from the multilevel model in the bottom row of Fig. 4 (left). (We show these parameters for $\phi = 1$ because the estimates did not meaningfully differ across priors.) The average relation is neglibly small and closely centered on zero (with 93.8 % of the posterior distribution within $[-0.1, 0.1]$), suggesting that practically meaningfully large average relations are unlikely.

Second, the filled points and intervals show the partially pooled estimates of $\gamma_1 + \beta_2$ in visual comparison to their fixed effects counterparts from our main analysis (empty circles; Fig. 4). Partial pooling shrunk the

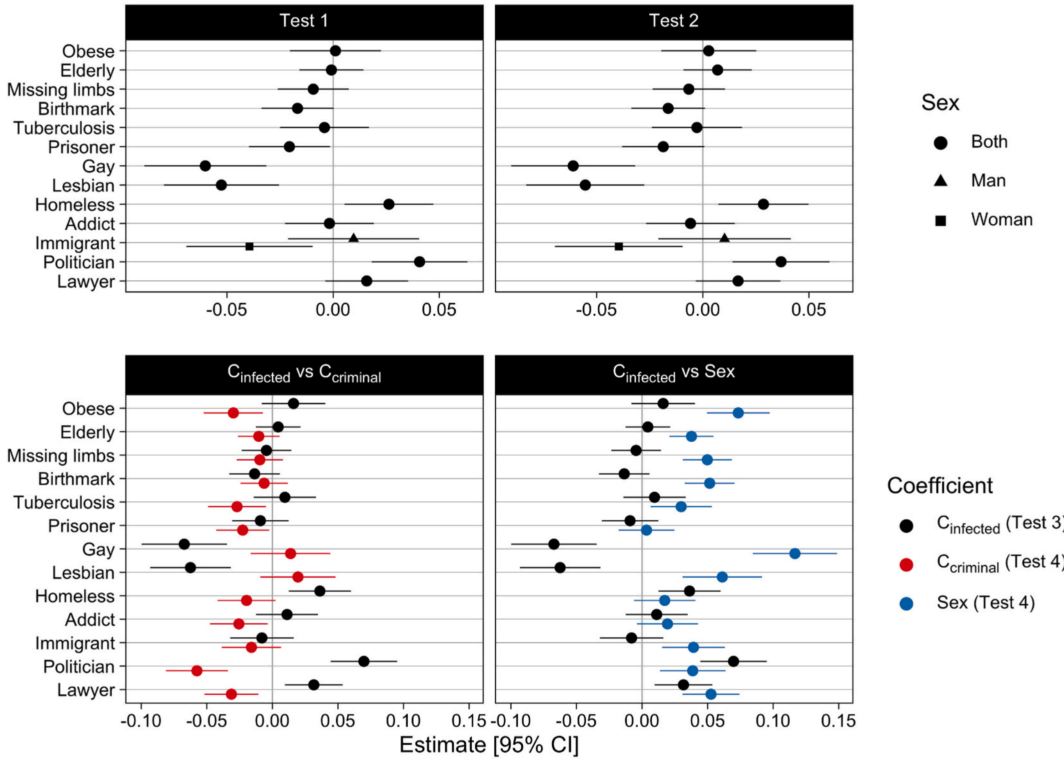

Fig. 3. Row 1. Regression coefficients of prejudice on $C_{INFECTED}$ relevant to tests 1 (adjusted for sex) and 2 (excluding individuals self-identifying with the target group). Row 2. Regression coefficients relevant to tests 3 (prejudice on $C_{INFECTED}$ adjusted for $C_{CRIMINAL}$ and participant sex) and 4 (comparing $C_{CRIMINAL}$ to $C_{INFECTED}$ and participant sex). Note: $C_{INFECTED}$ (black) is identical in the two panels to facilitate visual comparison to $C_{CRIMINAL}$ (left) and participant sex (right). More negative values for $C_{INFECTED}$ and $C_{CRIMINAL}$ indicate that bias toward seeing infection or criminal threats was related to greater prejudice toward the target group. Positive values for sex indicate that men reported greater prejudice than women.

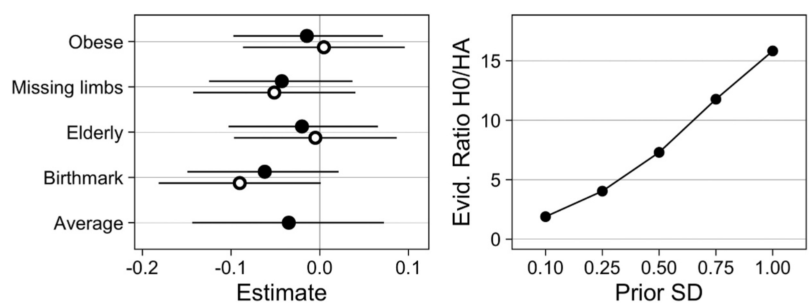

Fig. 4. Results from multilevel model assessing the relationship between $C_{INFECTED}$ and prejudice across target groups. Left: Estimated $C_{INFECTED}$ - prejudice relationships. Filled points indicate partially pooled target-group-specific estimates from multilevel model (with the average shown in the bottom row). Empty points indicate fixed-effect target-group-specific estimates of the corresponding models discussed in the main text. Note for the models here, we standardized prejudice scores. Right: Evidence ratio favoring the point null over the alternative (relationship is non-null), as a function of the standard deviation of the average relationship's prior distribution.

estimates toward their mean and subsequently provided more accurate estimates that avoid overfitting. Neither the average relation nor the group-specific relations were credibly different from zero at the 95 % confidence level.

Third, the right panel of Fig. 4 shows the evidence ratio between H0: $\beta_2 = 0$ and HA: $\beta_2 \neq 0$. Across the prior distributions that we considered, the evidence for the null hypothesis ranged from weak to very strong. We note that our numerical approximations to the evidence ratio are necessarily tentative because the prior distribution for β_2 is underdetermined by current theory but nevertheless take them to indicate moderate evidence against the smoke detector perspective of the relation between pathogen detection and prejudice.

4. Discussion

The present study investigated a prominent behavioral immune system hypothesis: specific appearance-based prejudices (e.g., prejudice toward obese people) result from an overly-sensitive sickness detection system. We conducted a cross-sectional study with participants from the U.S. in which we estimated relations between people's tendency to make false alarms in a sickness detection task and prejudice toward different social groups.

We first examined prejudice toward four groups arguably associated with anomalous appearances that could be (nonconsciously) interpreted as resulting from infectious disease: obese people, elderly people, people with a physical disability, and people with a facial disfigurement (H1). We detected an association in the predicted direction for only one out of the four groups (people with a facial disfigurement). This relation became non-significant when controlling for people's tendency to make false alarms in a criminality detection task. Moreover, the relation was not credibly different from zero when we pooled information across the four target groups in a multilevel model. In terms of effect size, the findings are equivocal: The sex difference in prejudice was greater than the relation between $C_{INFECTED}$ and prejudice; relations between prejudice and $C_{CRIMINAL}$ and $C_{INFECTED}$ did not differ significantly. Together, our results provide neither strong nor consistent evidence for the hypothesis that prejudice toward groups associated with anomalous appearance can be explained by a more sensitive sickness detection system. In fact, our exploratory Bayesian analysis showed moderate evidence against a relation of non-negligible size.

Confidence in the validity of these results is buttressed by multiple findings that align with observations in previous work. For example, women reported higher pathogen disgust sensitivity compared to men ($d = 0.34$). Perhaps more importantly, those who are more easily disgusted by pathogen cues tended to interpret ambiguous targets as more likely to be sick ($r = 0.10$). We also found that participants' responses in the sickness detection task closely matched performance reported in previous studies using the same stimuli. For example, we observed a sensitivity index of $d' = 0.38$, which was very similar to the sensitivity index observed in previous work using the same stimuli ($d' = 0.41$; Axelsson et al., 2018). Overall, these "positive controls" suggest that the lack of support for H1 cannot easily be attributed to poor data quality or measurement error.

Analyses of prejudice toward additional target groups (H2, H3, and H4; see Fig. 2) were included to facilitate interpretation of the evidence for H1 (i.e., to evaluate the extent to which the relation between bias to detect pathogens and prejudice extends to groups beyond those mentioned in H1). Given the weak evidence for H1, the interpretation of these analyses is not entirely straightforward. We found no support for the prediction that a tendency for false alarms in the sickness and criminality detection tasks relates to prejudice against sick people or criminals, respectively (H2). Previous studies suggest that the behavioral immune system might also give rise to prejudice toward other groups not characterized by an anomalous appearance (e.g., immigrants). Results were only partially consistent with this idea (H3). We also assessed prejudice toward two additional groups for whom prior research provides no clear rationale for pathogen-motivated prejudice (lawyers and politicians; H4). In line with expectations, we did not detect relations between prejudice toward these groups and the tendency to make false alarms in the sickness detection task. Exploratory analyses in which we estimated the effect across our four primary target groups (H1) with a Bayesian multilevel model also yielded results consistent with this conclusion. These results showed that the average relation between the sickness decision criterion and prejudice is close to zero. In sum, results did not support the possibility that variability in the tendency to make false positives in a disease-detection task relates to prejudices putatively motivated by pathogen avoidance mechanisms.

What are the implications of these findings? First, the weak support for H1 could, of course, partially reflect false negatives. Second, the largely-null findings reported here suggest that this research area would benefit from future work evaluating alternative theories and models (see Section 1.2) for explaining the observed relations between pathogen avoidance motivations and prejudice. In other words, while pathogen detection can be modeled as a signal detection problem, the relation between pathogen avoidance and prejudice might not arise as a byproduct of signal detection components of pathogen detection. Third, the behavioral immune system literature might benefit from reevaluating the degree to which aspects of human psychology result from general tendencies to commit Type 1 versus Type 2 errors when evaluating disease risks. For certain relations (e.g., offspring, romantic partners), Type I errors (treating a noninfectious individual as infectious) might exceed the costs of Type II errors (treating an infectious individual as noninfectious). Indeed, variation in willingness to engage in microbe-sharing contact varies strongly as a function of a target's interpersonal value (Tybur et al., 2020). Future work could generate and test a taxonomy for how cost asymmetries vary across situations and social relationships. Fourth, pathogen-avoidance mechanisms might generate responses that inhibit microbe transmission but do not neatly fit with the notion of prejudice. When opportunities for cooperation are scarce but beneficial (or even essential), blanket negative evaluations of infectious individuals might be more costly than beneficial. For example, a person might willingly assist a sick neighbor with errands while simultaneously avoiding close proximity. This form of behavioral distancing allows individuals to preserve reciprocal social ties without incurring unnecessary health risks. The distinction between affective prejudice and strategic avoidance is supported by findings that people often express support for stigmatized groups (e.g., the homeless) in abstract or policy terms, while avoiding close physical interaction (Clifford & Piston, 2017). Just as error management likely varies across contexts, pathogen-avoidance responses to infectious individuals might be calibrated to context-specific trade-offs between health protection and social cooperation.

4.1. Limitations

Measurement issues could have attenuated the observed correlations, leading to false negative inferences. However, the reliability and distribution of scores suggest that measurement error is unlikely to be a serious limitation. Our study sampled participants from one country: the U.S. Therefore, findings are limited to the U.S. population and might not generalize to different populations.

Because the current study did not test the three components (disgust, atypicality detector, and cognitive appraisal) described by Oaten et al. (2011), its results cannot speak to the overall accuracy of that model. Although the present results do not support the idea that false alarms to detecting illness relate to prejudice, they do not constitute evidence against the three-component model as a whole, nor do they rule out independent or interactive contributions of its constituent parts to stigma and discrimination. An important limitation concerns the construct validity of the sickness detection task itself. Participants were asked to judge whether target individuals were "sick" or potentially contagious. While the stimuli were ecologically grounded—featuring real inflammatory responses—the response prompt may have elicited judgments shaped by participants' explicit beliefs about illness, contagion, and the germ theory of disease. These judgments might not have mapped perfectly on the perceptual or inferential systems that underlie the smoke detector principle, particularly if there are disjunctions between conscious reflection upon the folk concept of "sick" and mechanisms that detect sickness. Future work could refine such tasks by distinguishing between judgments rooted in explicit disease reasoning and other approaches.

5. Conclusion

People who are more disgust-sensitive tend to be more prejudiced toward gay men (Kiss et al., 2020; van Leeuwen et al., 2022) and other social groups. Common targets of prejudice, such as people with obesity and homeless people, evoke disgust (Clifford & Piston, 2017; Inbar & Pizarro, 2021; Park et al., 2007; Vartanian, 2010) or are explicitly associated with infectious disease (Kurzban & Leary, 2001; Oaten et al., 2011). These findings have motivated the hypothesis that the behavioral immune system—a suite of psychological mechanisms for detecting and avoiding disease threats—contributes to the formation of specific social prejudices. We conducted a high-powered, registered test of a central prediction derived from this perspective: that individuals with a more liberal sickness detection criterion (i.e., a tendency to infer infection on the basis of ambiguous cues) would exhibit stronger prejudice toward groups with anomalous appearance. Despite a robust design and multiple analytic approaches, we found little support for this hypothesis.

While our findings do not rule out all pathogen-related accounts of prejudice, they are not consistent with the view that perceptual bias in sickness detection is a primary mechanism underlying the link between pathogens and prejudice. Future work may benefit from considering alternative routes through which prejudice might flow from the behavioral immune system.

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CRediT authorship contribution statement

Florian van Leeuwen: Writing – review & editing, Writing – original draft, Project administration, Methodology, Investigation, Conceptualization. **Bastian Jaeger:** Writing – review & editing, Methodology, Formal analysis, Conceptualization. **John Axelsson:** Writing – review & editing, Methodology. **D. Vaughn Becker:** Writing – review & editing, Methodology. **Lina S. Hansson:** Writing – review & editing, Methodology. **Julie Lasselin:** Writing – review & editing, Methodology. **Mats Lekander:** Writing – review & editing, Methodology. **Matti Vuorre:** Writing – review & editing, Methodology, Formal analysis. **Joshua M. Tybur:** Writing – review & editing, Methodology, Conceptualization.

Declaration of competing interest

None.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.evolhumbehav.2025.106716.

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