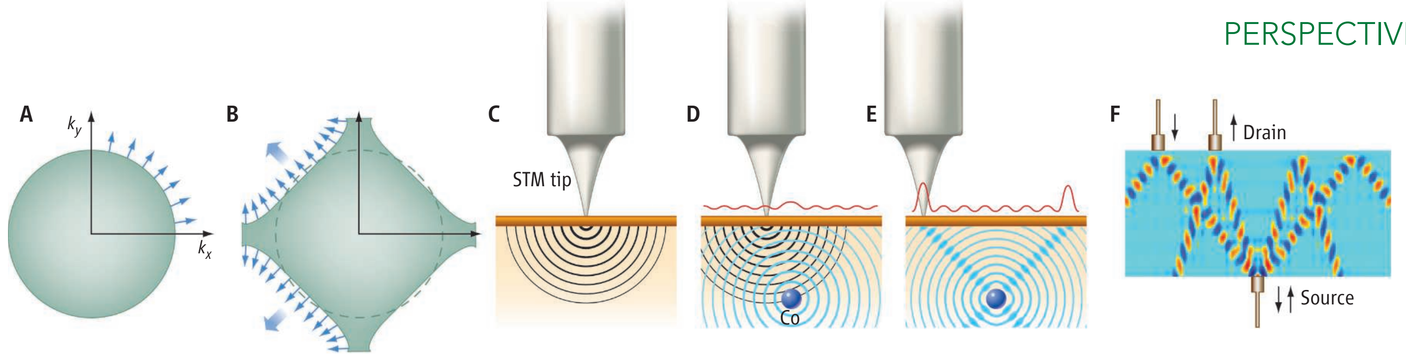

Scattered electrons. (**A**) A nearly-free-electron gas has a spherical Fermi surface. The blue arrows indicate the direction of electron propagation at the Fermi surface. (**B**) In the cartoon model of the Fermi surface of Cu, certain directions become preferred due to the nonspherical shape of the Fermi surface. The thick arrows indicate directions of electron focusing. (**C**) In a typical STM experiment on a metal, an electron tunnels into the surface and becomes a bulk electron wave whose amplitude decays with distance. (**D**) When a scatterer is present under the surface, the electron wave can be reflected. For a spherical Fermi surface, this results in a weak interference pattern at the surface. (**E**) When the Fermi surface is not spherical, electron focusing is observed along certain directions, which can give rise to a pronounced interference pattern observable at the surface. (**F**) Theoretical prediction of separate interference patterns for different spin channels in a magnetic material [from Weismann *et al*. (*1*)].

This wave behavior of the electrons in the bulk of the sample is not visible in most STM images and is thus typically neglected in the analysis of STM experiments.

The situation changes dramatically when a point defect is incorporated under the surface. Such a defect can scatter the electron waves emanating from the tunneling tip. The reflected wave can interfere with the incoming wave, giving rise to a standing-wave pattern that can be seen at the surface. For the case of a spherical Fermi surface, the amplitude of the scattered electron wave decays rapidly, and only a very weak interference pattern can be expected on the surface (see the figure, panel D). Weismann *et al.* see a dramatic increase of this interference pattern at the surface for Co atoms buried several layers underneath (see the figure, panel E), and argue that this can be understood from the shape of the Fermi surface: Along certain spatial directions, the amplitude of the scattered wave decays very slowly (arrows in panel B; see supplementary movies S1 and S2). In essence, the electrons are scattered along beams of electron waves, a phenomenon referred to as electron focusing. When these beams intersect the surface of the material, a strong and characteristically shaped interference pattern is observed. This interference pattern reflects information about the propagation of electrons through the bulk of the material—and hence on the shape of the Fermi surface—and the strength and type of scattering potential below the surface. Weismann *et al.* show that these interference patterns can be accurately calculated by incorporating a very large number of atoms in the sample.

The observation of electron interference patterns on surfaces with STM goes back to the beautiful standing-wave patterns of electrons confined to the inside of a quantum corral on copper (*4*). More recently, the wave nature of electrons in two-dimensional electron gases at surfaces has been used to perform electron holography (*5*) and to study the electron propagation in high-temperature superconductors (*6*). In the latter case, one can deduce a plethora of spatially resolved information on the electron behavior in such partially disordered systems with complex electron-electron interactions.

Weismann *et al.* also use their calculational approach to highlight a wide range of exciting future experiments. They discuss the fact that electrons of different spin character in magnetic materials generally have differing Fermi surfaces. This should enable the observation of separate interference patterns for injecting minority spin versus majority spin electrons (see the figure, panel F). The technique may also be used to study buried interfaces with high spatial resolution. The system used in the present study is a prototypical Kondo system—a single magnetic impurity in a sea of electrons—and one should be able to obtain deeper insights into electron scattering above and below its characteristic magnetic transition temperature. Interpreted correctly, one can therefore judge a book by its cover.

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Supporting Online Material

www.sciencemag.org/cgi/content/full/323/5718/1178/DC1
Movies S1 and S2

10.1126/science.1170744

PSYCHOLOGY

From Oral to Moral

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Is moral disgust an elaboration of a food rejection system?

The term "disgusting" is applied to bad tastes, cockroaches, incest, and proposing an unfair division of money in an ultimatum game. Is the emotional response the same in all four cases? On page 1222 of this issue, Chapman *et al*. (*1*) show that there is activation of a muscle central to the facial expression of disgust in response to unfair treatment (divisions of money), and argue that it "elicits the same disgust as disease vectors and bad tastes." What does that mean, and how would you demonstrate it?

One possible model to consider is a temporal analysis of disgust comprising three layers. At the top are the elicitors of disgust. To one degree or another, these trigger a set of mental activities that can be considered a "disgust evaluation system" (see the figure) that appraises the elicitor, generates a sense of offensiveness and revulsion, and leads to thoughts of "contamination." Psychological contamination refers to the feeling or belief that when something offensive touches something else, the offensiveness is transferred to the contacted object (thus, when a

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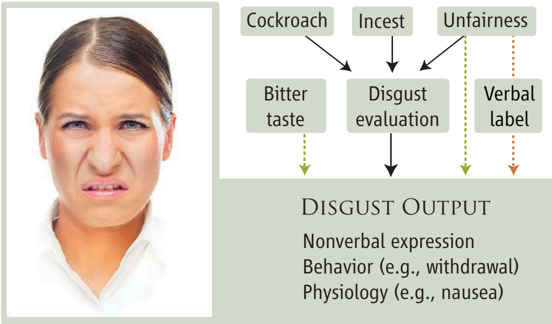
sterilized cockroach is dipped into a glass of juice, the juice becomes offensive). This neural system in turn triggers a disgust output program, including emotional expressions, behaviors, and physiological responses such as nausea.

According to the principle of preadaptation, a system that evolves for one purpose is later used for another purpose. From this viewpoint, disgust originates in the mammalian bitter taste rejection system, which directly activates a disgust output system. This primal route (e.g., bitter and some other tastes) evokes only the output program, without a disgust evaluation phase. During human evolution, the disgust output system was harnessed to a disgust evaluation system that responded not to simple sensory inputs (such as bitter tastes) but to more cognitively elaborated appraisals (e.g., a cockroach). Initially, the evaluation system was a food rejection system that rejected potential foods on the basis of their nature or perceived origin. This was the first "true disgust," because it engaged this evaluation system. Later, through some combination of biological and cultural evolution, the eliciting category was enlarged to include reminders of our animal nature, as wel as some people or social groups (*2*). This process had adaptive value, because by making things or thoughts disgusting a culture could communicate their negativity and cause withdrawal from them.

It has also been proposed that the disgust evaluation system was further extended (*2*, *3*) to a class of moral offenses involving violations of purity and sacredness, described by anthropologist Richard Shweder as "the ethics of divinity" in a taxonomy of three widely found clusters of moral meanings (*4*). However, recent evidence indicates that disgust may also be elicited by violations of fairness and justice (Shweder's ethic of autonomy). Autonomy violations are typically associated with anger (*3*).

According to a possible three-layer scheme of disgust analysis, there are three pathways through which an elicitor could activate the disgust output program (see the figure). The core route elicits a set of disgust evaluations (appraisals, feelings, and contamination cognitions), which in turn lead to the disgust output. What about routes involving moral violations of incest and unfairness? It may be that incest and other corporeal (divinity) violations activate the disgust evaluation system, just as do elicitors of core disgust. If unfairness and other moral violations that have no corporeal element trigger the disgust evaluation system, then they represent the furthest expansion of the "oral to moral" evolution of disgust. But does the evidence of Chapman *et al.* indicate such an expansion?

Alternative views by a number of scholars propose that the link between morality and disgust is largely a metaphor (*5*), construed as such because it bypasses the disgust evaluation system. But the link is not "just" a metaphor. Unfairness and other moral violations may directly affect the disgust output system, after processing by some other evaluation system, or these violations might simply activate the verbal label "disgust," which would then activate the disgust output system. The outcome of either route would include the facial expression of disgust. The Chapman *et al.* observations are consistent with both these alternative routes as well as the one that uses the disgust evaluation system. But only if evidence is found for a route from unfairness to the disgust evaluation system can it be concluded that disgust at unfairness is "the same" as disgust that is elicited through the core route (such as in response to cockroaches).



Domains of disgust. The schematic represents routes by which eliciting situations may trigger the disgust output program. Those that run through the disgust evaluation system—which includes appraisal of the elicitor, feelings, and contamination ideation—trigger the full disgust emotion. Solid lines represent routes through which an elicitor can activate the disgust evaluation-output program. Dashed lines (green) represent direct elicitation of the disgust output program. The dotted line (brown) represents a metaphoric, indirect route.

There is evidence that violations of the ethics of divinity (especially violations of food and sex taboos) engage the full disgust evaluation output. People feel disgust for divinity violations (*3*). There is also a link between incest and oral inhibition (such as nausea, gagging, and loss of appetite) (*6*). And contaminating cognitions accompany divinity violations (*7*).

A few studies suggest that fairness violations might indeed activate the disgust evaluation program, at least to some degree. Cleansing actions (related to purity and divinity) influence moral judgments about autonomy as well as divinity violations (*8*). Priming disgust, through exposure to disgust-eliciting material, makes subsequent moral judgments of both divinity and autonomy violations more severe (*9*). Divinity and fairness violations activate parts of the brain (particularly the anterior insula) that are also activated by core disgust (*10*), but the anterior insula is not uniquely associated with disgust (and vice versa).

If Chapman *et al.* are correct in that unfair divisions of money activate "the same" disgust as is activated by cockroaches, then it is almost surely mixed with anger, the prototypical emotion for autonomy violations (*3*). Anger is also an emotion that often activates the raised upper lip (*11*), the main disgust marker that Chapman *et al.* relied on. Until studies examine the effects of a variety of elicitors on a variety of dependent measures (e.g., contamination, appraisals, and feelings), it is unclear whether it's "the same" disgust, or just some common elements in the output system. Moreover, there are probably important variations in the evaluative and output systems for different types of disgust (*12*).

Even if the evolutionary and development history of disgust is indeed "oral to moral," it does not follow that a modern person's experience of moral disgust has to have an oral aura. But it appears that there is quite a bit of oral in moral experience, almost certainly for divinity violations and perhaps even for autonomy violations.

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