**Sensory malfunctions, limitations, and trade-offs**

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**Abstract** Teleological accounts of sensory normativity treat normal functioning for a species as a standard: sensory error involves departure from normal functioning for the species, i.e. sensory malfunction. Straightforward reflection on sensory trade-offs reveals that normal functioning for a species can exhibit failures of accuracy. Acknowledging these failures of accuracy is central to understanding the adaptations of a species. To make room for these errors we have to go beyond the teleological framework and invoke the notion of an ideal observer from vision science. The notion of an ideal observer also sheds light on the important distinction between sensory malfunction and sensory limitation.

**Keywords** Sensory error · Representation · Visual illusion · Sensory malfunction · Dretske · Matthen · Sensory limitation · Sensory trade-off · Sensory ecology

**1 Introduction**

Like beliefs, sensory states seem to be representational in nature. That is, they seem to be the kinds of things appropriately assessed in terms of correctness or accuracy. After all, we routinely make use of this kind of normative assessment when explaining behavior. Just as we sometimes make sense of errors in goal-directed behavior by invoking incorrect belief, so too we sometimes explain inaccurate responses to a perceptual task by appeal to inaccuracy at the sensory level. Think of the task errors human and non-human subjects make when confronted with standard illusions in experimental settings.

 An important philosophical question about sensory representation concerns the standards relative to which accuracy is assessed. Where do these standards of accuracy come from? What is their origin? One widely held view is that they derive from the biological functions of sensory systems (e.g. Dretske 1986, 1988, 1995, Matthen 1988, Neander 1995, 2013). Sensory error occurs only when sensory systems fail to do what they were selected to do. This teleological approach to sensory normativity treats normal functioning for a species as a kind of standard: sensory error involves departure from normal functioning for the species, i.e. sensory malfunction.

The teleological approach yields a powerful framework for making sense of task errors. Not only does the framework afford a principled basis for determining whether a task error is due to error at the sensory level; it also allows us to acknowledge another important source of task errors, namely, sensory limitations. After a brief overview of the teleological approach to error in section two, I introduce the idea of sensory limitations in section three.

In spite of its attractions, the teleological approach is not without its difficulties. In section four I argue that it has trouble accommodating sensory trade-offs. Straightforward reflection on sensory trade-offs reveals that normal functioning for a species can exhibit failures of accuracy. Acknowledging these failures of accuracy is central to understanding the adaptations of a species. Since teleological theories tie inaccuracy to malfunction, they are ill-equipped to accommodate sensory errors due to evolutionary trade-offs. My positive proposal for addressing trade-offs draws on the notion of an ideal observer from vision science. An ideal observer, I suggest, sets the standard required to make sense of error in the absence of malfunction.

**2 Sensory Malfunctions**

In what follows I am going to assume that sensory states are appropriately assessed in terms of accuracy. This assumption is plausible: some failures in goal-directed behavior evidently trace back to inaccuracy at the sensory level. At the same time this assumption is far from trivial. If standards of accuracy are going to help explain successes and failures in goal-directed behavior, they presumably need to be standards *in rerum natura*—not standards imposed or created by us. It is hardly obvious that there are standards suited to play the required role.

Dretske (1986, 1988: 63, 1995: 8) proposes that natural standards of representational success and failure are present wherever organisms have structures devoted to relaying information about the environment. What these structures are *supposed* to do is fixed by their historical function, what they were selected to do. Talk of *representational error* is appropriate when information-conveying structures fail to do what they are supposed to do. Dretske (1995:5) sums up the proposal as follow:

Sensory organs and mechanisms are commonly described in terms of what they are ‘for’... This way of describing perceptual mechanisms and processes is a representational way of thinking about them. The senses yield representations of the world, not just because they (when working right) deliver information about the world, but because that is their job. The senses, and the states they produce by way of performing their function, are thus evaluable in terms of how well they do their job.

On this way of thinking about sensory normativity, all genuine cases of sensory error are instances of malfunction, departure from normal sensory functioning for the species in question.[[2]](#footnote-1)

Sensory malfunction or error can take a variety of forms. One broad type commonly acknowledged by advocates of the teleological approach is failure of function due to an abnormal state of the sensory system itself. Sometimes sensory systems malfunction from the start thanks to congenital disorder. Sometimes they come to be defective or damaged[[3]](#footnote-2) through senescence, injury, disease… In addition to these more or less permanent disorders, sensory systems can become temporarily abnormal through prolonged exposure to a stimulus, sensory deprivation, drug use… In all these ways a sensory system can fail to do what it is supposed to do.

 Another broad type of sensory malfunction is that due to abnormal viewing conditions,[[4]](#footnote-3) ways that the viewing conditions differ from those prevailing in the creature’s natural habitat. The illusion of depth that occurs in viewing images with a stereoscope exemplifies this type of error.

Matthen (1988) notes that there is a kind of failure of sensory function additional to these two kinds involving abnormality. Sensory systems often have to rely on imperfect sources of information about the distal environment. For example, human color vision relies on a proximal stimulus which conflates information about surface color and illumination. So while human color vision has the function of telling us about surface color and illumination, it sometimes fails to fulfill this function even under perfectly normal conditions. We misperceive a surface-color gradient as an illumination gradient or misperceive an illumination gradient as a surface-color gradient.[[5]](#footnote-4) Since the human visual system is failing to perform its function, it makes sense to speak of *malfunction* or *error* even though nothing abnormal is going on. Matthen refers to these sensory errors as *normal misperceptions*.

 We now have an overview of the teleological approach to sensory error sufficient for our present purposes. Error amounts to nothing more than failure of biological function. In the following section I introduce an additional way that the teleological framework can shed light on task errors. The framework, I suggest, allows us to draw an important distinction between failures of function and limits of function. Acknowledging limits of sensory function allows us to make sense of a wide range of task errors.

**3 Sensory Limitations**

In a provocative discussion of the topic of visual illusion, Rogers (2010) introduces the notion of a facsimile, an artefact capable of producing a proximal stimulus which is an exact match with the proximal stimulus yielded by a real scene. For example, a perfectly constructed Ames room is a facsimile of a corresponding rectangular-shaped room. It is typical for researchers to regard Ames rooms as illusions and the percepts they generate as illusory. Rogers resists this natural way of thinking, denying that facsimiles give rise to sensory errors.[[6]](#footnote-5) Unfortunately, his remarks in defense of this claim, while suggestive, are somewhat obscure.

 The teleological framework provides theoretical support for Rogers’ claim about facsimiles. Presumably no visual system has the function of differentiating facsimiles from their corresponding real scenes. Since vision is confronted with the same proximal stimulus in each case, it is simply not suited to the task. But if visual systems are not in the business of differentiating facsimiles from their corresponding real scenes, failure to do so is not a failure of function. And if there is no failure of function, the teleological framework provides principled grounds for denying error.

 The case of facsimiles serves to illustrate a more general point. When we are thinking about the function of a sensory system, we need to distinguish limits of sensory function from failures of sensory function (i.e. sensory malfunctions or errors). Sensory limitations are among the contours that serve to define an organism’s sensory capacity or function. They are constitutive of normal functioning, not departures from normal functioning. I have in mind limitations like our inability to discriminate subthreshold differences among stimuli. Although these limitations give rise to task errors, they are not instances of malfunction. They are sensory limitations, not sensory errors.

 One way to make the idea of sensory limits more precise is to invoke the notion of an ideal observer from vision science. An ideal observer is “a hypothetical device that performs optimally in a perceptual task given the available information and any specified constraints” (Geisler 2011). What counts as optimal performance on a given task will depend on the perceiver’s goal,[[7]](#footnote-6) the information available to the perceiver, and any constraints imposed by things like the anatomy of the eye and neural noise. Once we have settled these matters, we can exploit Bayesian decision theory to determine optimal performance on the task, how an ideal observer would respond to the task. My suggestion is that an ideal observer’s performance serves to demarcate an important kind, namely, sensory limitation. That is, the task errors of an ideal observer indicate sensory limits rather than sensory errors. We should hesitate to acknowledge sensory error here because we do not have any standard of perceptual performance relative to which an ideal observer falls short. An ideal observer performs optimally in its sensory discriminations. Accordingly, there does not appear to be any *sensory* failing. Gilchrist (2006: 274) likely has something like this point in mind when he describes the task errors of an ideal observer as *legitimate* errors. The ideal observer, as a kind of standard, *legitimizes* responses even when those responses to the task are incorrect.[[8]](#footnote-7) There is no sensory error because the task errors of an ideal observer mark limitations of function, not failures of function.

 At the outset I noted that we sometimes appeal to sensory error to explain task errors. A more revealing thing to say is that we sometimes appeal to sensory error to explain deficient performance on perceptual tasks. Performance counts as *deficient* provided it falls short of a relevant ideal observer, an ideal observer with the same goal, information, and constraints as the actual subjects in question. Acknowledging sensory error is important because it is sometimes needed to explain perceptual performance that is suboptimal. I myself am doubtful that there is any other legitimate purpose served by positing sensory errors.[[9]](#footnote-8)

We saw in the previous section that sensory malfunction takes several forms. The same is true of sensory limitation. On my proposal, the task errors of real subjects can be attributed to sensory limitation whenever those errors are non-coincidentally common to a relevant ideal observer. Sensory limitations differ in kind depending on whether the limits displayed by the ideal observer in question trace back to specific constraints or to impoverished information. I will provide illustrations of each type in turn.

Sometimes a limitation stems from what Geisler (2003: 826) calls “biological constraints,” constraints imposed by things like “the optics of the eye, the spatial arrangement of the photoreceptors, and their spectral sensitivities” (cf. Geisler 2011, 773). The phenomenon of metamerism illustrates this type of sensory limitation. Error on color matching tasks (metameric matching) is often a consequence of constraints imposed by the biological structures supporting all color vision in the natural world. Biological color vision depends on a visual system’s integration of signals from a limited number of opsin-based receptors. In the course of normal functioning these receptors are routinely stimulated in the same manner by lights differing in spectral composition. When metameric matching is a product of constraints imposed by the biological substrates of color vision, these task errors are naturally regarded as products of limitation of function.

One might resist this way of thinking about metamerism. One might insist that it is the function of color vision to afford discrimination of spectral differences and that metamerism amounts to failure of function, i.e. sensory error. I am inclined to reject this alternative on the grounds that it depends on an overly simple characterization of the function of color vision. It is not the function of biological color vision to register any and all spectral differences. Our inability to discriminate differences in the UV range is not a failure of function. Human color vision was not put together for that purpose. The same can plausibly be said about our inability to tell metamers apart. We are running up against a limitation of biological color vision.

A further example should help to clarify my stance on metamerism. Consider the task of identifying a match in intensity or brightness for a target light cast upon a wall. Weber’s law has the consequence that some incremental differences in intensity discernible when the target is less bright will prove to be indiscernible when the target is brighter. The task of making precise matches becomes progressively more difficult as we increase the brightness of the target. The upshot is that normal human subjects fail to discriminate physically different light intensities. I think we should resist the suggestion that failure to perceive these subthreshold differences is a matter of failure of function, and my reasoning parallels what I said in the case of metamerism. *It is not the job of our visual system to register any and all differences in light intensity*. Rather, our visual system seems to have the function of tracking something like *proportional* changes in light intensity.

So one kind of sensory limitation is limitation due to constraints imposed by things like receptor sensitivity, internal noise, and neural summation. A further type is sensory limitation due to impoverished information. The case of facsimiles discussed above is an illustration of this type of limitation. *Any* observer charged with the task of visually discriminating facsimiles from their corresponding real scenes will be susceptible to error—even an ideal observer constrained only by laws of nature. So the limitation should be attributed to impoverished information and not to any specified constraints.[[10]](#footnote-9)

It is interesting to note that there are at least two other ways to address facsimiles within the teleological framework. First, since facsimiles are artefacts, things like Ames rooms, we could say that they give rise to abnormal viewing conditions. In the case of an Ames room, we could say that sensory error occurs thanks to the subject’s unusually restricted viewpoint on an artificially constructed environment. Placed in these unnatural conditions, the subject misrepresents the space as rectangular. Second, we could say that a facsimile like an Ames room gives rise to normal misperceptions. The visual system goes wrong because it is relying on an imperfect source of information about the distal environment—one susceptible to facsimiles!

One way to keep limitations and malfunctions straight is to insist that we acknowledge sensory malfunctiononly when *sensory deficiency* is present. A sensory deficiency is a deviation from the sensory state of a relevant ideal observer, where that deviation results in a task error the ideal observer would not make. The idea is that we only need to invoke malfunction when performance is suboptimal. When performance non-coincidentally matches that of a relevant ideal observer, there is no need to posit error at the sensory level. Adopting this proposal would allow us to maintain that the task errors brought on by facsimiles are due to sensory limitation rather than sensory malfunction.

I will not attempt to defend this proposal here.[[11]](#footnote-10) For my present purposes it is not important how, exactly, we should draw the line between sensory limitations and sensory errors. It is sufficient that we have some idea what the distinction between limits of function and failures of function comes to. What I will argue is that some task errors do not stem from either limits or failures. I believe these task errors pose a serious challenge to the teleological framework.

**4 Sensory Trade-Offs**

Many errors on perceptual tasks are products of compromise. Sensory systems are needed for a variety of different tasks, which can place competing demands on those systems. One familiar example of a trade-off along these lines is that between visual sensitivity and resolution. Achieving better spatial resolution often comes at a cost to sensitivity, and *vice versa*. For example, some nocturnal predators like the barn owl have a visual system which emphasizes sensitivity to light at the cost of fine spatial resolution (Orlowski et al. 2012). The owl’s performance in detection tasks is improved at the cost of visual discrimination of fine detail.

So one kind of compromise involves two or more tasks imposing conflicting requirements. Another kind occurs when achieving both accuracy and speed on a given perceptual task are in tension with one another. Sometimes a gain in accuracy comes at the cost of processing speed, and *vice versa*. For example, nocturnal bees have increased accuracy in dim illumination at the cost of having “slower” photoreception than their diurnal counterparts, while diurnal insects adapted for high-speed pursuit or avoidance sacrifice accuracy for the sake of speed (Chittka et al. 2009).

 Although speed is the factor most often emphasized in discussions of trade-offs involving accuracy, no doubt there are other ends for which accuracy can be sacrificed. One obvious example is conservation of energy. The metabolic costs of of maintaining and deploying sensory systems are known to be considerable (Laughlin 2001). Niven et al. (2007) suggest that trade-offs between energy cost and perceptual performance are widespread. There is every reason to expect that conserving energy sometimes has costs with respect to accuracy.

Sensory trade-offs generate a serious worry about the adequacy of teleological theories of sensory normativity.[[12]](#footnote-11) Even when trade-offs have been optimized relative to fitness, they nonetheless involve genuine costs. And in some cases we are dealing with genuine costs with respect to accuracy at the sensory level. Since the loss in accuracy can be part of normal functioning for a species, teleological theories are unable to acknowledge these costs for what they are, namely, costs with respect to accuracy. We need a standard of accuracy relative to which these costs can be assessed, and the teleological framework is not in a position to deliver. On the teleological approach, normal functioning for a species is the standard: all failures of accuracy are ultimately failures of biological function. But sensory errors due to evolutionary trade-offs are distinct from failures of function. They need not involve any abnormalities or imperfect cues.

Sensory ecology is a discipline devoted to identifying the variety of perceptual tasks animals rely on in their natural habitats, and to describing and explaining the diversity of sensory powers deployed in the performance of these tasks. One important way sensory ecologists explain sensory differences in nature is by appeal to trade-offs (Stevens 2013, Cronin et al. 2014). By their nature, evolutionary trade-offs involve costs with respect to attributes like resolution, sensitivity, and accuracy. Sensory ecology requires a standard by reference to which costs with respect to accuracy can be measured, and the teleological framework is ill-placed to provide what is needed.

One significant part of achieving a comprehensive understanding of the sensory adaptations of a species is grasping the extent (if any) to which potentially conflicting goals like speed and accuracy have come to impact perceptual accuracy. A crucial benchmark is provided by the performance of an ideal observer with the goal of maximizing accuracy on the task in question. We can, in principle, attain genuine insight into the adaptations of a species by comparing the performance of this ideal observer with the performance of an ideal observer aimed at the more complex goal for the species in question, a goal balancing competing ends like speed and accuracy. (Within Bayesian decision theory, these more complex goals can be represented by way of a cost function reflecting the weighted loss associated with inaccurate responses and longer response times. See Geisler 2003: 826.) Comparing the accuracy rates of these models provides some measure of the impact the trade-off has had on accuracy.[[13]](#footnote-12)

I have just introduced two ideal observers for a given task: one with the goal of maximizing accuracy on the task; the other with a more complex goal reflecting a compromise between competing aims, including the aim of accuracy. Why treat the former as a standard? Why not instead appeal to the latter and suggest that the task errors due to the trade-offs in question express sensory limitations shared by an ideal observer? The problem with this alternative suggestion is that it fails to acknowledge the real costs of trade-offs. In the cases of interestwe cannot adequately appreciate the adaptations of a species without recognizing compromised accuracy for the sake of other gains. We need to posit a further standard of accuracy—an ideal observer tailored for the goal of maximizing accurate responses—in order to secure the desired conclusion that the loss is one of accuracy.

I conclude that sensory errors due to evolutionary trade-offs constitute a kind distinct from both sensory malfunction and sensory limitation. They constitute a type of sensory error, one that the teleological framework has no obvious way to accommodate. To make room for these errors we have to go beyond the teleological framework and acknowledge ideal observers as standards of accuracy.

**Acknowledgements** This paper has been significantly improved thanks to expert feedback from two anonymous referees. I greatly appreciate their advice and patience. I also wish to thank Marc Artiga and Ben Bronner for valuable written comments on an earlier version of this paper. Finally, thanks to Dorit Ganson for encouragement and discussion of the issues.

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2. For my purposes it is important to emphasize the species-relative character of normal functioning. For discussion see Gauker 2011: 199. [↑](#footnote-ref-1)
3. For a helpful illustration, see Neander’s (2013: 33) discussion of neurologically damaged toads. [↑](#footnote-ref-2)
4. Dretske (1988: 68) calls these *unnatural circumstances*. He has in mind conditions which divorce “a sensitive biological detector” from “the habitat in which it developed, flourished, and faithfully serviced its possessor’s biological needs.” Matthen (1988: 12) refers to these as cases of *maladaptation*: “if a system is exposed to environmental circumstances to which it is not adapted, circumstances manufactured by a laboratory worker for example, then it may be ‘fooled.’” [↑](#footnote-ref-3)
5. See Matthen 2010 for a more detailed explanation of exactly what form this visual misrepresentation takes. For my response, see Ganson 2013. [↑](#footnote-ref-4)
6. Rogers is talking about the perception of a match between the shape of an Ames room and the shape of the corresponding rectangular-shaped room. He is not talking about the familiar size distortions generated by Ames rooms. [↑](#footnote-ref-5)
7. For example, in a two-choice detection task requiring subjects to determine whether a stimulus is present, the perceiver’s goal might be either to maximize accuracy or to minimize expected costs (relative to a specific cost function). [↑](#footnote-ref-6)
8. See also Gauker 2013: 204-5. Gauker suggests that, in taking legitimate task errors to be errors, we may well be importing a standard derived from human *judgment*.Gauker makes this proposal in the context of accounting for what he calls *persistent illusions*, illusions like the Müller-Lyer which do not involve any functional abnormality. I think Gauker’s approach to persistent illusions is a powerful way to address legitimate errors. I depart from Gauker on the issue of how to understand what he calls “mere misperception” (194-200), i.e. error at the sensory level. Gauker takes errors of this sort to involve departures from what is normal for a species (199). I argue against this general approach in §4 below. [↑](#footnote-ref-7)
9. Mendelovici (2013) brings up the interesting possibility that color vision might always and everywhere misrepresent the world because there are in fact no colors in the world. The teleological framework does not have any obvious way of acknowledging such errors as errors. They are not due to abnormality and they are not normal misperceptions as Matthen understands them. I myself do not share Mendelovici’s worry because I am inclined to acknowledge sensory error only when doing so will help to explain deficient performance on perceptual tasks. This response to Mendelovici concedes that there may be error at the level of thought. Descartes famously denies that color experience is systematically in error while maintaining that everyday thinking about color involves a mistake. See Ganson & Ganson 2010. For discussion of a different set of objections to Mendelovici, see Artiga 2013 and Mendelovici 2016. [↑](#footnote-ref-8)
10. For other potential examples of sensory limitation due to impoverished information, see the literature suggesting that standard illusions are byproducts of optimal solutions to ambiguous stimuli: Weiss et al. 2002, Geisler and Kersten 2002, Corney and Lotto 2007, Brown and Friston 2012, and Lupyan 2015. [↑](#footnote-ref-9)
11. No doubt some readers will prefer to think of facsimiles as giving rise to sensory errors. I set this issue aside because it does not affect my central thesis thesis that teleological theories are inadequate. [↑](#footnote-ref-10)
12. For a criticism of Dretske similar to the one that follows, see Shin 2003: §3.6. Shin’s argument depends on a hypothetical example adapted from Godfrey-Smith 1992. [↑](#footnote-ref-11)
13. Of course, we are likely to gain greater insight into the accuracy costs of the species’ adaptations when our models are biologically more realistic (i.e. when the models include biological constraints). [↑](#footnote-ref-12)