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Chapter 3

Top-Down and Bottom-Up Influences on Observation: Evidence from Cognitive Psychology and the History of Science

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The hypothesis that theories might influence observation was proposed in the important early work of Hanson (1958) and Kuhn (1962). It has been brought to a new focus by the interchanges between Fodor (1984, 1988) and Churchland (1979, 1988). Fodor has argued that perception is not cognitively penetrable, while Churchland has argued for a strong form of theory-ladenness. This issue has led to very heated debate in the philosophy of science because many scholars have felt that if observation is theory-laden there can be no neutral observation data, and this leads to epistemological relativism. We wish to criticize two assumptions that have been made in this debate.

Overemphasis of the Role of Visual Perception

First, we think that the emphasis on visual perception and scientific observation reflects a narrowing of focus that began in philosophy with the British Empiricists, became very strong with the work of the Logical Positivists, continued undiminished with the anti-Positivist work of Kuhn and Hanson, and remains strong today in the debate between Fodor and Churchland.

Several scholars have recently pointed out that data in modern science are typically not based on the perceptual experience of the scientist. Bogen and Woodward (1992) provide a very powerful analysis of the types of information used in scientific practice and conclude that, "It is data rather than perceptual beliefs that play a central evidential role in science and data are typically not descriptions of perceptual appearances or reports of perceptual belief at all" (p. 599). And Fodor (1991), with typical flair, has dramatically undercut the relevance of his modularity approach for the philosophy of science by changing his position and adopting the view that the data that constrain science are often not perceptual.

In a recent paper Brewer and Lambert (2001) also argue for a more delimited role of perception in the scientific process. However, they place this point in a much larger context. They argue that a naturalized philosophy of science must examine the scientific process from the initial designing of experiments to the final writing of journal articles. They show the role of top-down theory-driven processes across a number of the mental activities involved in doing science with an analysis of the relevant literature from cognitive psychology and some selected cases from the history of science. They argue that, in addition to their role in perception and attention, top-down processes play a major role in: (a) data evaluation, (b) data production, (c) memory, and (d) communication.

Brewer and Lambert conclude that theory-driven processes probably play their largest role in the interpretation and evaluation of data. They review a large literature in cognitive psychology showing that top-down information can play a powerful role in the understanding of texts. For example, in the classic study of Bransford and Johnson (1973) participants had trouble understanding sentences such as "The notes were sour because the seam was split" unless they were given the appropriate conceptual framework (e.g., bagpipes). They describe a study by Brewer and Chinn (1994) that showed the role of theory in the evaluation of data in a situation that was designed to be close to the process of data evaluation by scientists. Brewer and Chinn taught one group of participants the theory that dinosaurs were warm blooded and taught another group of undergraduate participants that dinosaurs were cold blooded. Then each group was given the same piece of additional data to evaluate. This data was either consistent or inconsistent with the theory they had been taught. The results showed that the data were evaluated quite differently by the two groups. The data were considered much more likely to be true when it was consistent with the theory the participants had been taught earlier.

Brewer and Lambert (2001) showed that there were similar top-down effects in memory, suggesting that scientists are more likely to recall information that is consistent with their theoretical beliefs. Therefore when two scientists with different theoretical views are using the scientific literature to reason about a scientific controversy they will be bringing different evidence to mind. Finally, Brewer and Lambert point out that the organization and information included in a scientific report are highly theory-laden.

Even though Brewer and Lambert (2001) provide much evidence for the important role of theory-laden processes throughout the scientific enterprise, they also point out that the social institutions of science (e.g., peer review, journal publication) and methodological procedures developed by scientists (e.g., keeping lab notebooks, use of control samples, use of double blind procedures) have been designed to reduce some of the potential problems associated with the theory-laden processes.

In discussions of the theory-ladenness of perception, the implication is often that theory ladenness is a Bad Thing that must somehow be excluded from the scientific process so that we can have an objective science based on theory neutral data. It seems to us that this is an incorrect view about the role of top-down processes in science. Top-down processes can play *either* a facilitative or inhibitory role in cognitive performance and in the activities of the working scientist.

We think that the general solution to this complex issue is that when the top-down processes are consistent with the state of the world they facilitate and when they are inconsistent with the state of the world they tend to be inhibitory. Thus when Leverrier used Newtonian mechanics to predict the existence and location of an unknown planet it gave Johann Galle an enormous advantage over other astronomers in knowing where to look to discover Neptune, while having a theory about the existence and location of the planet Vulcan (a planet that was hypothesized to lie between Mercury and the Sun) led to many false observations of this planet. For a theory that corresponds to the state of the world, top-down processes facilitate the doing of science across the range of scientific practice, but a theory that does not correspond to the state of the world can retard scientific activity across the same range of scientific practices.

ECOLOGICAL VALIDITY IN THE STUDY OF SCIENTIFIC PRACTICE

The second assumption we want to criticize is that psychological experiments dealing with the early stages of the perceptual process are relevant to epistemological issues in the philosophy of science. In the field of cognitive psychology there has been an important controversy over the appropriate strategy to be used in carrying out research. In 1978 Ulric Neisser introduced the issue of ecological validity into the area of memory research with a powerful paper titled "Memory: What are the important questions?" This paper argued that many laboratory memory tasks were not appropriate to answer the important questions in memory research. Brewer (2001) characterized the general argument for ecological validity as an argument that there should be a convincing link between the experimental tasks the scientist uses and the phenomena in the world that the scientist is trying to understand. In the history of psychology there have been a number of occasions when this link was not present. For example, for decades, investigators studying human memory focused their efforts on narrow laboratory tasks using nonsense syllables as stimuli. It is clear that the goal of these investigators was to develop a general understanding of human memory, yet due to the lack of ecological validity of their laboratory tasks, their research was unable to address issues such as the powerful role of syntax, word meaning, and schemata in the everyday operation of memory.

We think the ecological validity argument can be used to provide a very powerful critique of some of the evidence used in recent naturalized approaches to the philosophy of science. Fodor (1983, 1984) and Raftopoulos (2001a, 2001b) have provided detailed analyses of the data from cognitive psychology and neuroscience on the processes involved in the early stages of visual processing. This issue is of vital interest to the psychologist attempting to give an account of human vision, but it is not relevant for the core issues of theory ladenness in the philosophy of science. The ecological validity argument as applied to the issue of the theory ladenness of observation requires that the naturalistic data used be relevant to the types of tasks that scientists carry out. Our earlier argument that most scientific observation is nonperceptual suggests that the appropriate research would be studies relevant to the task of how the scientist reduces data gathered by various types of instruments. However, for the moment, we will ignore that line of argument and focus on the subset of observing tasks where the data actually are perceptual observations by scientists.

From our point of view, the only experimental literatures in the area of perception that are relevant to the philosophy of science are those that deal with end products of the perception of objects in the world, since that is what scientists are using to carry out their investigations. In order to attempt to find a stage of perception that is not theory laden, both Fodor (1983) and Raftopoulos (2001a, 2001b) consider the possibility that there is a point in the visual process that corresponds to Marr's 2 1/2 D sketch, and both argue that perception at this stage is not cognitively penetrable. We think the use of this type of naturalistic evidence is completely undercut by the ecological validity argument. For the relevant issues in the philosophy of science, we do not care about the path leading up to the final perceptions of the scientist; we are only interested in the final product of the perceptual process. We feel that for a valid naturalized philosophy of science one must use the empirical studies that are appropriate for the task one is trying to understand.

The ecological validity argument also undermines the attempt by many philosophers to distinguish between sensation/early perception and observation/cognition/inference. Here the attempt is, once again, to find a form of data that is not theory laden. However, the ecological validity argument shows that we should only be interested in the scientist's final observation, and if it is theory laden (as we will show later in this chapter) then so be it. In "The Modularity of Mind" (1983) Fodor has attempted to show that the perceptual modules are encapsulated by interpreting (selected) evidence for top-down processes as due to inferences from the central systems. Once again it seems to us that the ecological validity argument as applied to the philosophy of science undermines the relevance of this strategy.

We think that the ecological validity argument undercuts the attempt to use the modularity approach to save perception from theory. However, in the later sections of this chapter where we review the evidence from cognitive psychology we will ignore these powerful arguments against the application of modularity and attempt to engage the modularity hypothesis on its own ground. Fodor (1988, p. 197) states that "the outputs of modules are judgments about how things appear," and we aim to show that there are clear data showing theory ladenness at the level of "how things appear."

TOP-DOWN BOTTOM-UP SYNTHESIS

During the Behaviorist era and during the early days of Information Processing approaches in experimental psychology, the dominant model of the operation of the mind was a bottom-up, inflow model. The Behaviorist approach was bottom-up because physical stimuli were taken to be the data of psychology, and the Behaviorists adopted an inflow model because their world view tried to reduce or eliminate higher cognitive processes and therefore the individual was treated as a passive recipient of the incoming physical stimuli.

During the early days of the Information Processing revolution, some of the restrictions imposed by the Behaviorist world view were softened or eliminated, but the bottom-up, inflow architecture of the mind remained (e.g., Gough, 1972). The flavor of this early approach can be seen in a comment Gough made during the discussion of his paper. In the discussion, Brewer (1972) provided examples from the experimental literature showing that there were top-down conceptual influences on reading (e.g., the difficulty in catching typographical errors during reading for meaning; evidence that letters are recognized better in words than in nonwords, etc.). Gough rejected this evidence because he could not "see how the syntax can go out and mess around with the print" (Brewer, 1972, p. 360), and his argument found overwhelming support from the other experimental psychologists who were present during this debate.

However, as more experimental evidence for top-down, conceptually driven effects became available, a new consensus developed in which perception/observation was conceived as the product of both bottom-up and top-down factors (e.g., Lindsay & Norman, 1977, p. 251). This view became even stronger when new architectures were developed (McClelland & Rumelhart, 1981) that gave a natural account of the top-down, bottom-up synthesis. The view was given additional support from neuroscience with the realization that there was much evidence for top-down descending neural pathways in the visual system (cf. Churchland, 1988).

In recent times Jerry Fodor has been a major force in transmitting experimental findings from cognitive psychology into a naturalized philosophy of science. Fodor (1983, 1984, 1988) has argued that the evidence supports a view that the mind is composed of informationally encapsulated modules. Note that in many ways Fodor's view is a regression to the earlier positions that existed before the development of the top-down, bottom-up synthesis. There are a number of reasons why Fodor has developed this approach, but the one of most interest to the philosophy of science is that by showing that perception is not cognitively penetrable Fodor and his Granny (Fodor, 1984) hoped to show that there are theory-neutral observations upon which to base science and thus to stop the slide to relativism. Fodor's arguments have had a major impact on philosophy of science, and a number of recent papers on naturalized philosophy of science (e.g., Gilman, 1990; Raftopoulos, 2001a, 2001b) have argued that the evidence from cognitive psychology and neuroscience is strongly in favor of Fodor's view.

In the next sections of this chapter we counter the modularity view and argue for the top-down, bottom-up synthesis. In doing this we are not taking an extreme position. Examination of current textbooks in cognitive psychology will show that the top-down, bottom-up synthesis is the default approach in cognitive psychology. It is only because of Fodor's strong presence in philosophy that a neutral reader of the current literature in the naturalized philosophy of science would think that the evidence from cognitive psychology supports the modularity approach. In reviewing the literature in cognitive psychology we will focus on the role of top-down effects in perception because we want to counter the argument that perception is not cognitively penetrable. However, we will also lightly discuss evidence for bottom-up effects since that is part of the top-down, bottom-up synthesis. We also want to emphasize the important point that one need not be frightened of evidence for top-down effects in perception because the synthesis view allows one to accept top-down effects without sliding down the slope into relativism. In addition to the evidence from cognitive psychology we will include cases from the history of science that also support the top-down, bottom-up synthesis.

PERCEPTION: EVIDENCE FROM COGNITIVE PSYCHOLOGY

Top-Down Effects

Visual Illusions

Since the early work of Hanson (1958), evidence from perceptual illusions has sometimes been used to argue for the existence of top-down processes in perception. For example, Rock (1983) and Churchland (1988) argue that illusions such as the reversible Necker Cube and the apparently unequal line lengths in the Müller-Lyre figure occur because the visual system has theoretical information (built in or acquired) about the laws of optics.

Fodor (1984, 1988) agrees that these illusions may show some forms of low-level theory within the perceptual module. However, he points out that this is not the kind of flexible, high-level theoretical knowledge needed to argue that the top-down effects studied in experimental psychology are analogous to the hypothesized impact of scientists' theories on their observations. And he notes that, in fact, these types of illusions are strongly resistant to flexible, high-level knowledge. If one measures the two lines in the Müller-Lyre illusion and comes to believe that they are actually of the same length, this higher-level knowledge does not eliminate the illusion. Clearly these types of visual illusions are not cognitively penetrable in the way that they should be for the standard theory-ladenness position. Thus we agree with Fodor that these illusions should not count as evidence for the traditional theory-ladenness position. However, in the next sections we show that there are many examples of experiments that *do* show the impact in visual perception of just the kind of high-level theoretical knowledge that has been postulated by those who have argued for the theory-ladenness of perception.

Two Classes of Stimuli

Some of the clearest effects of theory on perception have come through the use of vague or ambiguous stimuli. The distinction between *vagueness* and *ambiguity* comes from linguistics, though it can equally be applied to pictures. Vague stimuli are stimuli for which the interpretation seems unclear or unconstrained. An example would be an out-of-focus photograph (e.g., Bruner & Potter, 1964). Ambiguous stimuli are stimuli that are not degraded, but can be interpreted in more than one way. An example of an ambiguous figure is the classic Old Woman/Young Woman drawing that can be seen as an old woman or a young woman (Boring, 1930).

Vague Stimuli

Bruner and Potter (1964) hypothesized that early incorrect identification of a vague stimulus might interfere with eventual correct identification. They showed observers sequences of views of a picture (e.g., a bird in the sky, a fire hydrant) that started with a very blurred version and then continued with increasingly less blurred versions of the picture. They compared (at a common level of blur) the object recognition accuracy of those observers who had originally seen more blurred versions with those who had originally seen less blurred versions. They found that the observers who began by seeing images that were quite blurred showed lower recognition accuracies than those who began with less blurred pictures. They argued that the observers who began a series with a very blurred picture had very little bottom-up information to work with and so often developed top-down perceptual hypotheses that were very different from the actual objects in the unblurred pictures. These incorrect top-down perceptual theories then interfered with their ability to perceive the bottom-up perceptual information. This is a case where theories that were at variance with the world caused observers to have difficulty with veridical perception. Luo and Snodgrass (1994) made some methodological improvements in the Bruner and Potter experiment and replicated the finding that prior exposure to more degraded images reduces correct object recognition.

Another type of degraded stimulus that has been studied is the fragmented figure. Reynolds (1985) carried out a study with fragmented figures in which observers were given different amounts of top-down information. One group was not informed that the apparently random set of black and white patches were fragments of a meaningful picture. When interviewed after the experiment only 9% reported seeing any meaningful pictures. Another group was informed that the patches were fragments of meaningful pictures. With this quite limited amount of top-down information, picture identification rose to 55%. A final group of observers were given information about the conceptual class of the fragmented picture (e.g., they were told *an animal* for a picture of a dog) and this increased their successful picture identification rate to 74%. This is a case where the groups given theoretical information consistent with the world showed theory-based facilitation. It is unlikely that these results are due to nonperceptual inferences. These pictures were developed to study perceptual reorganization, and the phenomenological experience with a successful recognition of a fragmented figure is that the random fragments are suddenly perceived as a meaningful object.

Ambiguous Figures

A number of studies have been carried out on the impact of top-down information on the perception of ambiguous figures. One set of studies (Goolkasian, 1987; Leeper, 1935) has used top-down *visual* information. These studies presented observers with an unambiguous version of an ambiguous figure (such as the Old Woman/Young Woman) and then later showed the observers the ambiguous form. This type of top-down information has an enormous impact on what the observers see when presented with the ambiguous picture. Essentially all of the observers who had previously seen an unambiguous picture of an Old Woman saw the ambiguous figure as an Old Woman and essentially all of the observers who had previously seen an unambiguous picture of a Young Woman saw the ambiguous figure as a Young Woman. Once again this task is not one of conceptual inference--each of two alternate forms of the ambiguous figure gives rise to a qualitatively different perceptual experience. Notice that this experimental situation is analogous to a scientist who develops a visual skill through practice at looking at a particular class of objects through a microscope or from past experience in scanning pictures from a bubble chamber.

Bugelski and Alampay (1961) carried out an experiment with the Rat/Man ambiguous figure using a more conceptual form of top-down information. They showed one group of observers a set of animal pictures (not including a rat). This top-down information had a powerful impact; the number of observers who saw the ambiguous figure as a rat increased as much as 80% in some experimental conditions. Liu (1976) carried out a similar experiment but provided the top-down information in verbal form. She found that a group who heard a passage about rats before seeing the Rat/Man figure saw the picture as a rat twice as often as did a control group.

It seems to us that these studies of ambiguous figures are strong evidence for top-down influences on perception. The types of top-down knowledge involved are just the kind of high-level theoretical knowledge that Fodor (1984) argued was not involved in the case of perceptual illusions. In addition, the experimental tasks used in these studies do not easily allow Fodor to escape by interpreting the effects as merely an inference, since the observers in these experiments report qualitatively different perceptual experiences when they see one version of the figure or the other.

Anomalous Stimuli

Thomas Kuhn (1962) used the classic study by Bruner and Postman (1949) to make the point that top-down information can impair perception if the object to be perceived is inconsistent with pre-existing theoretical beliefs. Bruner and Postman presented observers with views of playing cards at brief exposures and asked them to identify the cards. Some of the cards were anomalous (e.g., a two of spades that was red). The thresholds for correct recognition were much higher for the anomalous cards than for the standard cards. This study is not as clearly a perceptual effect as the others we have discussed, but we have included it because of its important role in the history of the philosophy of science. It seems to us that one could argue against Kuhn's perceptual interpretation of the data and claim that the effects are simply due to the participants not being willing to report such an odd observation. Kuhn was probably aware of this alternate explanation, and to help counter it he gave examples of reports from the observers in the study that certainly sounded perceptual (e.g., "I can't make the suit out, whatever it is. It didn't even look like a card that time" Kuhn, 1962, p. 63). Bruner and Postman also report a variety of other data that suggest that the anomalous cards give rise to actual perceptual effects. When trying to describe an anomalous red spade, observers often reported unusual colors (e.g., brown, purple, rusty black) that were rare for the normal cards. We think the increased thresholds in this study are probably due to a mixture of true perceptual effects and report effects, and thus this experiment is not as analytic as some of the others we have discussed. However, note that if one applies the ecological validity argument, it does not matter. The experimental task is certainly analogous to some types of observation situations in science and suggests that scientists carrying out observations under nonoptimal conditions will be less likely to report anomalous observations, either because they have difficulty perceiving the information or because they do not think the evidence is sufficiently strong to risk reporting an anomalous finding. (They could be obeying the old dictum that "extraordinary findings require extraordinary data.")

Vague Scientific Stimuli

In discussing the issue of top-down effects, Fodor (1988, p. 194) gives knowledge of physics as the type of thing that could never lead to top-down effects on perception. Chinn and Malhotra (2002) carried out a fine experiment that we think comes very close to providing the type of evidence Fodor says cannot occur. Chinn and Malhotra assessed 4th grade children's naïve theories about falling bodies (i.e., does a heavier rock fall faster than a lighter rock). After finding out what the children believed, they carried out the Galilean experiment in front of the children by dropping two rocks (from a chair, not the Tower of Pisa) and letting the children judge if the rocks hit the floor simultaneously or if one hit before the other. In the actual conditions under which the experiment was carried out, the outcome was difficult to see. Chinn and Malhotra found that 72% of the children who held the theory that heavy and light rocks fall at the same rate, observed the rocks to hit at the same time, while only 25% of the children who held the theory that heavy rocks fall faster, observed the rocks to hit at the same time. Gunstone and White (1981) have reported similar findings. These studies certainly show that top-down beliefs about physics influence scientific observation and may well show that they influence the actual perception. In the next section we will examine evidence from cognitive psychology for bottom-up effects on perception.

Bottom-Up Effects

The evidence for bottom-up effects in perception is obvious. If one shows someone an apple in clear viewing conditions and asks what it is, clearly they will say "apple" and not "zebra." However, given the obviousness of the result, experimental psychologists (who have certainly sometimes been known to prove the obvious) have rarely made this the point of an experiment. Nevertheless, it is possible to show bottom-up influences using some of the same experiments discussed in the section on top-down influences on perception.

Thus, in the Bruner and Potter (1964) study, as the picture was brought into focus the percentage of observers who correctly recognized the picture increased as the level of blur decreased. So their recognition improved with increasing bottom-up information.

The ambiguous figures used in the ambiguous figure experiments (Bugelski & Alampay, 1961; Goolkasian, 1987; Leeper, 1935; Liu, 1976) show bottom-up constraints. Even though these figures are ambiguous, they are still tightly constrained by bottom-up information. Essentially everyone who views the Old Woman/Young Woman picture sees either an Old Woman or a Young Woman and no one sees a chair. The same obviously holds for unambiguous stimuli too; and, in fact, Bugelsky and Alampay point out that, under the conditions of their experiment, no observer misidentified any of the unambiguous animal pictures used to provide the top-down influences in that study.

The Bruner and Postman (1949) study also showed strong bottom-up effects--these just were not the aspects of the experiment Kuhn chose to emphasize. Bruner and Postman presented data showing that as the exposure time for the playing cards increased, the observers soon reached 100% accuracy for the normal cards and that by the time the exposure reached 1 second the observers were correct for most of the anomalous cards. There was another interesting top-down/bottom-up effect in the data. As soon as an observer correctly identified their first anomalous card correctly, their threshold for correctly identifying other anomalous cards dropped dramatically. Apparently as soon as the observers became aware that there were "trick" cards in the set, they were able to use this top-down information to facilitate the accurate processing of the bottom-up information from the anomalous cards. Clearly there are powerful bottom-up effects even for the very anomalous perceptual information used in this experiment designed to show top-down effects.

Overall, it seems to us that the data from the experiments on perception that we have just described provide strong evidence for the top-down, bottom-up synthesis. Now we will examine some episodes in the history of science that make the same case for the interplay of top-down and bottom-up factors in perception.

PERCEPTION: EVIDENCE FROM THE HISTORY OF SCIENCE

Top-Down Effects

One of the clearest examples in the history of science of top-down factors influencing perception is the discovery of N-rays (Klotz, 1980). In 1903 the French physicist Blondlot began studying the radiation generated by electric-discharge tubes. His technique for detecting possible radiation was to see if the new radiation increased the brightness of a spark jumping across a spark gap. He carried out a variety of experiments with this detector and soon announced he had discovered a new form of radiation--the N-ray. He worked out the properties of the new radiation (e.g., it could be refracted with an aluminum prism). Hundreds of experiments were published working out the properties of N-rays. However, the work came to an end when Wood, an American physicist, visited Blondlot's laboratory and found that the researchers in the laboratory could still see variations in the brightness of the spark gap when he had secretly modified the apparatus so that no N-rays could be falling on it. In retrospect, it appears that this episode in physics was a classic case of strong top-down theoretical beliefs influencing what the scientists saw when observing the spark gap. Notice that, as would be expected from the findings from cognitive psychology, the bottom-up information in this situation (small changes in the intensity of a spark gap) was very difficult to detect.

The history of astronomy is a very rich area for examples of top-down factors operating in perception. One example is Schiaparelli's observations on the rotation period of Mercury (Sheehan, 1996). Observing Mercury was a very difficult perceptual task because Mercury is close to the Sun. Schiaparelli stated that the marks on Mercury that he was using to judge its period of rotation were "extremely faint steaks, which under the usual conditions of observation can be made out only with the greatest effort and attention" (Sheehan, 1996, p. 69). Schiaparelli established that Mercury's period of rotation was 88 days and a number of astronomers around the world confirmed his observations. It is now known that the actual period of rotation is 58.65 days. In describing this consensus among observers Sheehan states "their results demonstrate only too clearly that once a definite expectation is established, it is inevitable that subsequent observers will see what they expect to see, refining their expectations in a continuing process until finally everyone sees an exact and detailed--but ultimately fictitious--picture" (p. 70).

Another example from the history of astronomy is the work of Adriaan van Maanen on the internal rotation of spiral nebulae (Hetherington, 1983). The task in this case was to compare very small differences in photographs taken at different times. After much careful work van Maanen announced that he had discovered rotation in one spiral nebulae and later replicated his findings with six more spiral nebulae. These data played a major role in early attempts to understand the structure of the universe. If it were possible to see rotation in nebulae then these nebulae could not be independent galaxies at enormous distances from us. Later work showed that the nebulae are, in fact, galaxies in an island universe so photographs taken at small time intervals could not show rotation. Initially astronomers attributed these erroneous observations to some form of equipment failure, but in more recent times they have been attributed to top-down factors. Hetherington (1983) states "clearly he had read his expectations into his data" (p. 728).

We have chosen these particular historical cases because, like the examples from cognitive psychology, they appear to show the top-down factors influencing the actual perception of the observing scientists. Note, as in the experiments from cognitive psychology, the strong effects of top-down factors occur in a context of weak bottom-up information. We assume that there are many cases in which the top-down factors have facilitated the accurate observations of working scientists, but it is difficult to find evidence for this effect. The operation of the top-down factors is excruciatingly obvious when later research shows that the world is not actually as it had been observed. In the next section we will examine the operation of bottom-up factors in the history of science.

Bottom-Up Effects

The discovery of the cosmic background radiation by Penzias and Wilson is a good example of bottom-up processes in science (Bernstein, 1993). These two scientists were working with a very sensitive antenna at Bell Labs and noticed that their antenna appeared to have too much noise. They spent most of a year trying to find the source of the unexpected noise. At one point they entertained the hypothesis that the noise resulted from pigeon droppings in the antenna! By chance they were referred to a group of scientists at Princeton who explained to them that the noise was probably not an artifact, but was a signal from leftover radiation after the Big Bang. There is another top-down, bottom-up irony to this story. The group at Princeton had developed a cosmological theory that predicted the cosmic background radiation and under the top-down influence of this theory was in the process of building a low-noise antenna to see if they could detect the background radiation. So if things had transpired on a slightly different time scale the discovery of the cosmic background radiation would have been a top-down discovery instead of a bottom-up discovery. In the next section we will examine evidence from cognitive psychology dealing with top-down effects on attention.

ATTENTION: EVIDENCE FROM COGNITIVE PSYCHOLOGY

The process of attention is tightly bound to the process of perception, so we will provide a brief account of the evidence for top-down and bottom-up influences on attention. Cognitive psychologists distinguish two forms of attention. Overt attention is measured by where a person looks. Covert attention is measured indirectly by showing perceptual enhancement of a target at an attended location (using probe discrimination or change detection for example) while a person's eyes are fixated elsewhere. Both forms of attention are strongly linked in normal perception, since the movement of the eyes to a target of interest is invariably preceded by shifts in covert attention.

Top-Down Processes

There are a large number of studies that show that observers pay more attention to theory-relevant stimuli than to theory-irrelevant stimuli. One group of researchers has studied this issue with simulated driving tasks. Pringle (2000) used a change detection task and found that observers were more likely to look at and detect a change to a driving-relevant stimulus (e.g., the color of a car's brake lights) than a driving irrelevant stimulus (e.g., the appearance or disappearance of a light pole). Theeuwes (1996) showed viewers brief film clips of approaches to intersections, and asked them to determine whether each film clip contained a stop sign or not. Viewers were more likely to look at and notice a stop sign when it was placed on the expected side of an intersection. Shinoda, Hayhoe, and Shrivastava (2001) had participants engage in a virtual driving task and asked them to follow all normal traffic laws. The experimenters then briefly changed signs that were located either at intersections or in the middle of a block from no parking signs into stop signs. Participants almost never failed to look at and respond to the stop signs at intersections, but missed more than 2/3 of the stop signs located in the middle of the block. Apparently the top-down information about the typical location of signs was directing attention so that signs with identical bottom-up sensory information in noncanonical locations were less likely to be seen and responded to.

Another way to study the role of top-down influences on attention is to compare groups that have different amounts of knowledge. Werner and Thies (2000) showed viewers scenes from American football games with changes that either would or would not affect the game's outcome and asked them to detect the changes. Viewers with more knowledge of American football were more likely to detect important changes than unimportant changes to a football scene. Football novices, however, were equally likely to detect both types of changes. Clearly there are powerful top-down effects on what and where an individual will focus attention.

Bottom-Up Processes

If attention were solely guided by top-down processes, people would be unlikely to notice important and unexpected information. In fact, some of the studies just reviewed suggest that this may occur more often than we would like to imagine (e.g., Shinoda, Hayhoe, & Shrivastava, 2001). However, there is also clear evidence of purely stimulus driven effects on attentional selection. A number of studies have shown that the sudden onset of information in a stimulus array can capture both overt and covert attention (Theeuwes, Kramer, Hahn, & Irwin, 1998; Yantis & Jonides, 1984). The likelihood of overtly or covertly attending to a location or object seems to be influenced by its relative visual saliency, as measured by its contrast with other regions of the visual field in terms of low-level visual features such as luminance, orientation, color, or motion (Itti & Koch, 2000; Parkhurst, Law, & Niebur, 2002). In this way, the bottom-up visual stimuli from the outside world can alter where and what we attend to. In the next section we will give examples of top-down attention processes at work in the history of science.

ATTENTION: EVIDENCE FROM THE HISTORY OF SCIENCE

Top-Down Effects

Almost any theory-directed observational discovery in science can be thought of as an example of the operation of top-down attention processes. One classic example was mentioned earlier--Leverrier used Newtonian theory to predict the location of a planet outside the orbit of Uranus (Grosser, 1979). When the German astronomer Galle directed his telescope to the location calculated by Leverrier he found Neptune almost immediately.

Another example can be found in the what astronomers call "pre-discovery" observations. After some astronomical object has been discovered astronomers around the world often do a top-down guided search through their data looking for pre-discovery observations of the new object. Clearly in these cases the relevant data had been recorded, but did not attract attention until there was a top-down reason to attend to certain locations on the old photographic plates.

Bottom-Up Effects

Röntgen's discovery of X-rays is an interesting example of the role of bottom-up effects in science (Nitske, 1971). Röntgen was carrying out experiments with cathode rays in a darkened room when he noticed a glow in a different part of the room. He was not expecting the glow, but it drew his attention, and he began trying to understand what was causing it. After a month's work in the laboratory he announced the discovery of X-rays. Even though his initial observation seems a good example of bottom-up information leading to an important discovery there were also interesting top-down factors at work. The observations he was making were so anomalous that he stated "I had to convinced myself repeatedly by doing the same experiment over and over and over again to make absolutely certain that the rays actually existed...Was it a fact or an illusion?" (Nitske, 1971, p. 5)

CONCLUSIONS

In our review of the empirical literature we have emphasized studies that show top-down influences on perception. From the large literature showing top-down effects we have selected examples where the top-down effects have qualitative perceptual consequences (e.g., the observer perceives an Old Woman). We wanted to avoid the escape by those trying to discount top-down effects that the top-down effects are due to interpretations of a theory-neutral perception. We also thought studies of this type would have the strongest impact on the view that perception is encapsulated and is not cognitively penetrable. Fodor (1988, p. 197) states that "the outputs of modules are judgments about how things appear" and we think the studies show that the way things appear can be modified by top-down conceptual information. Fodor (1988, p. 194) also argues that knowledge of physics is the type of knowledge from the central systems that can never influence perception. We think the evidence from Chinn and Malhotra (2002) and other studies shows that naïve theories of physics can certainly influence observation (which is the crucial issue for the philosophy of science) and may influence perception.

A number of philosophers influenced by Fodor have claimed that the literature in cognitive psychology supports the encapsulated view of perception. For example, Couvalis (1997, p. 14) states "There is no evidence that theory problematically permeates experience as opposed to merely helping us focus on some aspect of the world." We think the empirical studies we have discussed show that this interpretation of the perception literature within a naturalized philosophy of science needs to be revised.

Many philosophers of science from the time of the Logical Positivists have wanted to show that there was a hard rock of theory-neutral perception that could be used as the foundation for objective scientific knowledge. We think the evidence from cognitive psychology shows that this hope was not to be. However we think the evidence for top-down influences in the perceptual process does not have the grave epistemological consequences that many thought it would have. The examples of hallucinations and dreams show that perception can occur through totally top-down influences. However, we believe that in the usual case, bottom-up factors are the overwhelming influences on what we perceive. Examination of the experiments that found strong top-down effects on perception show that these effects are strongest when the bottom-up effects are the weakest--for example, when the perceptual information is degraded or ambiguous. Our review of the literature shows that strong, clear stimuli provide powerful bottom-up constraints on perception.

In general, we think the top-down, bottom-up synthesis provides a good account of the empirical studies of perception in current cognitive psychology. In addition we think this approach allows top-down factors but provides the bottom-up constraints necessary to avoid epistemological relativism. Similar arguments can be found in Brown (1977), Goldman (1986), Bechtel (1988), and Chalmers (1990).

We think the scientific community has understood that top-down factors can cause difficulty in scientific observation, and a number of scholars (Chalmers, 1990; Bogen & Woodward, 1992) have noted that many aspects of scientific methodology have been developed to reduce the problems that can result from these factors.

Our analysis of the functions of top-down influences in science also shows that theory-ladenness can facilitate attention and observation by scientists, if they happen to be lucky enough to hold theories that are consistent with the structure of the world.

Finally, we think our arguments for ecological validity in a naturalized philosophy of science are very compelling. Even if we are mistaken about the stage in human perceptual processing where top-down processes have their effects, it does not matter for the crucial issues in the philosophy of science. If future experimental work shows that the modularity view is correct, it will still be the case that the evidence of interest for the philosophy of science are the final observations made by scientists and the evidence presented in this chapter show that those observations are best accounted for by the top-down, bottom-up synthesis.

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