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The Role of Data and Theory in Covariation Assessment: Implications for the Theory-Ladenness of Observation

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The issue of the theory-ladenness of observation has long troubled philosophers of science, largely because it seems to threaten the objectivity of science. However, the way in which prior beliefs influence the perception of data is in part an empirical issue that can be investigated by cognitive psychology. This point is illustrated through an experimental analogue of scientific data-interpretation tasks in which subjects judging the covariation between personality variables based their judgments on (a) pure data, (b) their theoretical intuitions about the variables, or (c) both data and prior theoretical beliefs. Results showed that the perceived magnitude of correlations was greatest when subjects relied solely on theoretical intuitions; that data-based judgments were drawn in the direction of those prior beliefs; but that exposure to data nonetheless moderated the strength of the prior theories. In addition, prior beliefs were found to influence judgments only after a brief priming interval, suggesting that subjects needed time to retrieve their theoretical intuitions from memory. These results suggest ways to investigate the processes mediating theory-laden observation, and, contrary to the fears of positivist philosophers, imply that the theory-ladenness of observation does not entail that theoretical beliefs are immune to data.

According to Hanson's (1958) well-known thesis, all data are theory-laden in the sense that scientists' prior theoretical beliefs shape the observation of data. For both Hanson (1958) and Kuhn (1962), theories not only determine the meaning or interpretation of data, but also influence how the data are

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actually seen. These philosophers drew partial support for this view from evidence from the psychology of perception. More recently, a number of psychologists (Brewer and Samarapungavan, 1991; Clark and Paivio, 1989; De Mey, 1980, 1981) and philosophers (Bechtel, 1988; Churchland, 1989b; Giere, 1994) have followed the lead of Kuhn and Hanson in arguing that evidence from cognitive psychology is relevant to philosophical conceptions of theory and observation. More generally, there is growing agreement in both psychology (Freedman and Smith, 1985; Fuller, 1988; Gholson, Freedman, and Houts, 1989; Giere, 1988; Gorman, 1992) and philosophy (Bechtel, 1988; Fuller, 1988; Giere, 1988; Solomon, 1992) that research in experimental psychology has much to contribute to our understanding of the cognitive processes involved in science. Although psychological research cannot be expected to settle philosophical debates about ultimate issues (e.g., whether or not "pure" scientific observation is ever possible), the cognitive psychology of science can help reframe such issues and suggest new ways to analyze them. As an illustration of how such issues can be conceptualized from an empirical standpoint, the present paper reports an experiment in which subjects' prior beliefs could influence how they perceived data presented in graphical displays of the sort used in science.

The Theory-Ladenness of Observation

The Theory–Observation Distinction in the Philosophy of Science

Dating back to the logical positivists, it has been traditional among philosophers of science to draw a sharp distinction between theory and observation (Carnap, 1928/1969) as a way to preserve supposedly pure observation from the biasing effects of theoretical beliefs. The theory–observation distinction has more recently been invoked by philosophers such as Feigl (1970) and Fodor (1984) who challenge the theory-ladenness of observation on the grounds that a clear separation between theory and observation is necessary in order for the objectivity of science to be maintained. Feigl has suggested that if observation is theory-laden, then all theories become equally acceptable and there can be no method for deciding among competing theories. However, postpositivist philosophers such as Brown (1977) have noted that positivists have difficulty explaining how an ostensibly neutral observation can be associated with the relevant theory if data are completely divorced from the pertinent theory. Moreover, Weckert (1986) has argued that accepting the theory-ladenness of observation does not necessarily commit one to the sort of relativistic epistemology described by Feigl, because the fact that observation may be theory-laden need not in itself prevent the observation from having evidential impact on the status of a theory

(Brown, 1977; Scheffler, 1982). Indeed, even Hanson (1970) believed that theories must square with the facts. Thus, the theory-ladenness of observation does not necessarily eliminate the possibility that theories can be appraised on the basis of data that are colored by those theories.

One reason why the theory-observation distinction has produced so much debate among philosophers of science is that the basic assertion that all data are theory-laden is ambiguous. Grandy (1992) notes several different levels of possible theory-dependency. For example, he suggests that a theory could influence observation at either a perceptual or a conceptual (interpretive) level. In fact, philosophers have distinguished between observation — the act of seeing — and observational sentences that embody the act of interpreting observations (Grandy, 1992; Weckert, 1986). Clearly, Hanson (1958) believed that theory influences the interpretation of data as well as their perception; similarly, Weckert (1986) has argued that both observational sentences and observations are theory-laden. Beyond the act of viewing and interpreting data, Grandy also suggests that theory may influence observation through the choice of research instruments, measurement scales, linguistic expressions, or statistical analyses.

Perhaps misleadingly, much of the debate regarding the theory–observation distinction has focused on examples involving Gestalt figures or other ambiguous stimuli (e.g., the duck–rabbit) that permit fundamentally different dichotomous interpretations (De Mey, 1980, 1981; Hanson, 1958; Kuhn, 1962). In contrast to the examples employed by philosophers of science, scientific data are typically less ambiguous, in part because they often have some degree of quantitative precision. At the same time, quantitative scientific data vary continuously in the degree of fit between the predicted and actual findings. Consequently, quantitative data tend to be susceptible to varying degrees of interpretation rather than discrete either-or interpretations. Demonstrations of the theory-ladenness of relatively unambiguous quantitative data would increase the credibility of Hanson's (1958) thesis that the theory-ladenness of observation is a pervasive aspect of science, and not merely a phenomenon limited to Gestalt-like situations that afford two conflicting and mutually exclusive interpretations.

In our view, scientists' theories have a pervasive influence on their practices of determining the choice of instruments, dependent measures, and independent variables. In this article, we focus on the theory-ladenness of observation as it occurs in one narrower situation that involves the viewing and interpreting of data. Specifically, we are interested in a situation analogous to a scientist examining data portrayed in a graphical display. As noted by Cleveland, Diaconis, and McGill (1982), the graphical presentation of data is particularly relevant to scientific judgments because scientists are often presented with complex arrays of data about which they have prior theories. Another issue raised by the theory-ladenness thesis concerns the way in which the theory in question interacts with the available evidence. In philosophical accounts, the issue is whether or not an observation is influenced by the theories brought to bear on an observation. Yet, the degree to which the relative weight of theory and data influence the observation or interpretation of data has been ignored by philosophers. However, as will be elaborated in the following section, this issue has been addressed by psychologists.

The Psychology of Theory and Observation in Scientists and Laypeople

As numerous psychologists have noted (e.g., Alloy and Tabachnik, 1984; De Mey, 1980; McClelland and Rumelhart, 1981), perception generally involves a combination of top-down (or theory-driven) processes and bottom-up (or data-driven) processes. Bottom-up models assume that perception depends on how the perceiver combines the available information, usually in the form of simple features, into a meaningful percept. Top-down models assume that prior knowledge, theories, expectations guide the perceptual process. McClelland and Rumelhart (1981) have developed an interactive activation model that depicts perception as a combination of bottom-up processes and top-down processes. Specifically, they propose that the mental representations used in perceptual recognition are arranged in a multi-level hierarchical network. As data are initially processed, activation of a perceiver's mental representations spreads from the lower levels to the higher levels. In addition, activation subsequently spreads down from the higher levels to the lower levels so that mental structures involved in the perception of subsequent data are partially activated. Theory-driven observation occurs when an encounter with data serves to activate the mental representations that embody theories relevant to the observed phenomena (Churchland, 1989b; Giere, 1994). The specific mental representations activated will depend on the pattern of inputs (Churchland, 1989b; McClelland and Rumelhart, 1981; Palmer, 1978). Once activated, the representations affect how the available data are observed, typically by producing a selective encoding of information in the data that is consistent with prior theories (Alloy and Tabachnik, 1984). In this way, a perceiver's prior theories, once activated, can influence the observation of data in top-down fashion; at the same time, however, the data do constrain the way in which prior theories exert their influence, both by determining which theories become activated and by occasioning revisions in the theory when the fit between theory and data is insufficiently close.

Most cognitive psychologists, including those who study the psychology of science, believe that the mental processes underlying the interplay of theory and observation are essentially the same for scientists and everyday perceivers. This conviction is well supported by research on the theories that laypersons bring to the task of observation. For example, Brewer and Samarapungavan (1991) have argued that lay theories "embody the essential characteristics of scientific theories" (p. 209). Lay and scientific theories share a number of common characteristics including abstractness, globalness, and explanatory functions. In the case of scientific observation, the theories that drive perception are generally assumed to operate psychologically as mental representations (see Churchland, 1989b, 1992; Giere, 1994; Holland, Holyoak, Nisbett, and Thagard, 1986). Additionally, both everyday mental representations and scientific theories have been described as sets of propositions (J.R. Anderson, 1983; Giere, 1994), mental models (Holland et al., 1986), or patterns of connections within neural networks (Churchland, 1989a, 1989b). Thus, there is good reason to believe that the processes underlying theory-laden observation are essentially alike for everyday perception and scientific observation, and that the use of lay theories offers a relevant means of investigating the influence of theories on observation. (The rationale for using lay subjects in research on scientific inference is discussed in Gorman, 1992, and Shadish and Fuller, 1994; some of the empirical evidence on the similarity of laypersons and scientists in reasoning about data is presented in the Discussion section below.)

Social perception is one area in which the role of theories in everyday observation appears to parallel their role in scientific observation (Nisbett and Ross, 1980). There is considerable evidence that people have strong, naturally occurring intuitive theories about others in the social environment (Berman and Kenny, 1976), including implicit theories about how personality traits covary (Schneider, 1973). Despite some debate over the degree to which implicit personality theories are related to people's actual behavior, it is widely assumed that such theories involve mental representations and that these theories influence people's judgments of trait relationships (Berman and Kenny, 1976; Ebbesen and Allen, 1979). Following Tversky (1977), Borkenau (1986) has suggested that the mental representation of implicit personality theory is based upon the similarity of the traits. Consistent with feature comparison models of semantic memory (Smith, Shoben, and Rips, 1974), the similarity of trait pairs increases as a function of the number of overlapping features. Giere (1994) has likewise suggested that scientific concepts are mentally represented in terms of featural overlap.[1]

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[1]Laypeople's intuitive theories about such phenomena as personality traits may seem very different from the theories scientists typically bring to the task of observation, especially given that lay theories are likely to be less formal and explicit than scientific theories. But in terms of the issue addressed here, this seeming disanalogy is more apparent than real: the philosophical thesis of the theory-ladenness of observation is not limited to the effects of sophisticated formal theories, and indeed includes cases that would be considered relatively low-level

Viewed from a psychological standpoint, the bidirectional interplay of top-down and bottom-up processes in perception suggests that philosophical accounts of the theory–observation distinction are simplistic and miscast; especially problematic is the philosophical notion that the theory-ladenness of observation is an all-or-none affair. On the one hand, a psychological approach suggests that data inevitably interact with a perceiver's theories, because perception inherently depends on the activation of an individual's mental representations. On the other, the psychological perspective implies that the interaction of theory and data that occurs during the process of observation is a matter of degree rather than a complete subordination of observation to the demands of prior theory. Accordingly, the mutuality of theory-driven and data-driven processing implies that, contrary to philosophical concerns about the loss of objectivity, data can have an evidential impact on the credibility of a theory even when the observations in question are influenced by the theory.

From the foregoing discussion, it should also be clear that reframing the theory-ladenness of observation from a psychological perspective does not necessarily entail that observation is biased in any harmful sense. As Palmer (1978) notes, mental representations often accurately preserve the information in the world. Freedman and Smith (1985) have argued that scientific judgments are biased only when scientists misapply or overrely on specific cognitive processes. In a similar vein, philosophers such as Solomon (1992) have maintained that the epistemic value or harm of cognitive biases can be evaluated only from the perspective of a particular scientific community engaged in a specific research problem. The pervasive, perhaps inevitable, influence of theory on observation may stem in large measure from the crucial role played by theories — lay or scientific — in the organization of data and the management of complexity. As Faust (1984) notes, the complex, ambiguous, multidimensional nature of data necessitates that observers have a conceptual framework to guide their perceptions. The benefits of prior theories have even been demonstrated experimentally. Berman and Kenny (1976) found that strong implicit personality theories facilitate recall of trait information, and Wright and Murphy (1984) showed that prior lay theories actually increase perceivers'

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perceptual expectancies from a psychological standpoint (Bechtel, 1988). This can be seen in Kuhn's (1962, pp. 114–116) own extended example involving the rash of discoveries of planets that took place in the early 19th century. Following Herschel's celebrated discovery of Uranus in 1781, astronomers began to see the objects in their telescopes as planets instead of stars, even though the same objects had been observed repeatedly by earlier investigators who saw them as stars. In this example, which figures prominently in Kuhn's case for the theory-ladenness of observation, the relevant "prior theory" was simply that the solar system is populated with more planets than had previously been suspected.

sensitivity to systematic covariation, in part by making judgments more resistant to noise in the data (i.e., error variance and outliers). In sum, psychological research indicates that people's prior theories exist as mental representations, that these mental representations have a pervasive influence on the process of observation, and that such influence is by no means always detrimental to sound reasoning and cognition.

Covariation Assessment as a Model of Observation

Because many aspects of human knowledge — from simple perceptual learning to person perception and the higher forms of scientific reasoning — presuppose a sensitivity to simple associations between classes of events, the detection of covariation may represent a general and useful task for investigating the theory-ladenness of observation. More important for our purposes, previous authors (Alloy and Tabachnik, 1984; Jennings, Amabile, and Ross, 1982) have separated covariation assessment research into studies that focus on the role of data and studies that emphasize the influence of prior expectations or theories. Data-based studies examine people's ability to assess the relations among abstract variables when clear intuitions as to the direction or strength of those relations are lacking. In theory-based studies, the emphasis has been on understanding how subjects use their expectations, beliefs, and implicit theories in estimating the relationships among variables. Alloy and Tabachnik (1984) have argued that covariation assessment represents an interaction between the perceiver's theories and the objective relationships in the data, with the relative influence of theory and data depending on their prior strengths. Yet despite the recognition by psychologists that information processing involves a combination of data-driven and theory-driven processes, few studies have directly examined possible theory-data interactions (De Mey, 1980).

The Influence of Data on Covariation Assessment

Research on data-based covariation assessment has led to mixed results, with some findings indicating that people can accurately perceive the degree of objective covariation (Erlick, 1966; Erlick and Mills, 1967; Lane, Anderson, and Kellam, 1985) and some research suggesting that subjects have considerable difficulty estimating the amount of covariation, especially when they focus too narrowly on a subset of salient cases instead of all the data relevant to the task (Beyth–Marom, 1982; Jenkins and Ward, 1965; Smedslund, 1963; Ward and Jenkins, 1965). Several researchers (Bobko and Karren, 1979; Cleveland, Diaconis, and McGill, 1982; Lane et al., 1985) have found that subjects are sensitive to the amount of covariation in scatterplots, although their judgments are also influenced by the amount of apparent scatter independent of the degree of correlation.

The reported findings of inaccurate covariation estimation have led some authors (Jenkins and Ward, 1965; Nisbett and Ross, 1980; Peterson, 1980; Smedslund, 1963) to conclude that perceivers have little capacity to detect true covariation in the environment. Yet this conclusion may be premature given that several factors may have substantially impaired subjects' ability to detect covariation. For instance, sensitivity to the actual amount of covariation is greater when continuous variables are used (Cleveland et al., 1982; Erlick and Mills, 1967; Lane et al., 1985) than when dichotomous variables are used (Jenkins and Ward, 1965; Smedslund, 1963; Trolier and Hamilton, 1986). The presentation of data sequentially over time also reduces people's sensitivity to covariation (Jenkins and Ward, 1965; Smedslund, 1963; Ward and Jenkins, 1965) relative to that found in studies using simultaneous presentation in scatterplots (Cleveland et al., 1982; Lane et al., 1985), a finding that may be due to the added processing demands imposed by sequential presentation of data (Shaklee and Mims, 1982). It would thus appear that the simplest and most direct method for studying the influence of various factors on covariation assessment would involve the simultaneous presentation of continuous variables.

The Influence of Theory on Covariation Assessment

Although substantial evidence indicates that one's theories can affect the evaluation of some kinds of data (C. A. Anderson, 1983; Anderson, Lepper, and Ross, 1980; Lord, Ross, and Lepper, 1979), only a few studies have attempted to assess the relative influence of theories and data in covariation assessment (Billman, Bornstein, and Richards, 1992; Jennings, Amabile, and Ross, 1982; Trolier and Hamilton, 1986; Wright and Murphy, 1984). As Arkes and Harkness (1983) have noted, the role of prior theories in covariation assessment remains a worthy area for further research.

There has long been reason to believe that theories might have an impact on covariation assessment. Chapman and Chapman (1969) found that trained clinical psychologists perceived relationships between clinical symptoms and certain responses to psychodiagnostic tests where no relationships actually existed. They concluded that these "illusory correlations" arose from the psychologists' prior intuitive theories. More recently, Jennings et al. (1982) compared the role of prior theories and actual data in covariation assessment. In a data-based condition, subjects judged the degree of relationship in 10 pairs of bivariate stimuli (e.g., duration and pitch of musical tones) presented sequentially where no theoretical information was available. In a theory-based condition, subjects estimated the degree of relationship between specified pairs of meaningful variables (e.g., people's heights and weights) where no data were presented. Data-based judgments were systematically, even monotonically, related to the objective relationships. In contrast, theory-based judgments were not systematically related to the objective relationships. Instead, theory-based judgments often represented overestimates of the objective relationships, especially when the correlated variables concerned personality traits. Jennings et al. (1982) concluded that subjects' prior theories may free them from the constraints imposed by the data. However, the study conducted by Jennings et al. is limited because they asked subjects in the theory-based condition to judge the relations in variables without exposing them to any data. As a consequence, Jennings et al. were unable to examine possible data-theory interactions.

In studies that directly attempted to investigate possible interactions between theory and data (Trolier and Hamilton, 1986; Wright and Murphy, 1984), subjects judged the relatedness of sequentially presented number pairs exhibiting non-negative correlations. The role of subjects' prior theories was investigated by providing cover stories indicating that the numbers reflected variables about which the subjects had expectations. In both studies, raters proved to be sensitive to the covariation in the data. Judgments of covariation at all levels of actual correlation were higher when subjects expected the variables to be highly correlated (e.g., IQs of identical twins) compared to when subjects had no expectations (e.g., IQs of random pairs of students). Examining how different types of beliefs affect judgments of covariation, Billman et al. (1992) also found that data consistent with subjects' prior beliefs were rated more highly correlated than data not consistent with prior beliefs.

An Experimental Study of Theory-Laden Observation

The study that we present in this article differs in several ways from previous studies investigating the influence of prior theories on covariation judgments. First, in contrast with earlier experiments (Billman et al., 1992; Trolier and Hamilton, 1986; Wright and Murphy, 1984), our study compared covariation judgments across conditions that systematically varied subjects' access to data and theoretical intuitions. The roles of data and theory were investigated by soliciting judgments of covariation in four conditions: a data-only condition, in which judgments were made on the basis of scatterplots without knowing what variables were represented in the plots; a theory-only condition, in which judgments of the correlation between trait variables were made in the absence of any data provided by the experimenter; and two theory-plus-data conditions in which both data and theory were available. In one theory-plus-data condition, the trait labels and scatterplots were presented simultaneously. Because it is assumed that the trait relations are estimated through a feature comparison process (Borkenau, 1986; Smith, Shoben, and Rips, 1974), it was decided to include a second theory-plus-data condition in which subjects were given 30 seconds to think about the relationships between the traits prior to receiving the scatterplots. By virtue of the fact that the scatterplots used in the data-only and the theory-plus-data conditions were identical, we could determine how the presence of people's prior theories affected their assessment of the covariation. Use of the same trait pairs in the theory-plus-data and theory-only conditions allowed us to determine whether the presence of data has an impact on people's prior beliefs. In this way, the study allowed a determination of the relative contributions of theory and data to perceived correlations (see description in Methods section below).

A second difference between the present study and previous work is that the earlier investigators (Billman et al., 1992; Trolier and Hamilton, 1986; Wright and Murphy, 1984) used elaborate cover stories to generate different expectations about the levels of covariation. In addition to obviating the need for contrived cover stories, the use of personality traits in the present study provides a test of theory-based covariation assessment that more closely models the situation in science, where scientists typically approach the task of observation with preexisting theoretical beliefs intact. A third difference is that the present study examined judgments of negative correlations in addition to judgments of positive and zero correlations. As Wright and Murphy (1984) pointed out, "whether subjects can detect negative correlations as well as they do positive ones is an interesting question" (p. 305), and it is one that has rarely been investigated (see Erlick and Mills, 1967, for an exception). The inclusion of negative correlations also enhances the similarity of the task to scientific observation, where a full range of relationships between variables can and does occur. Fourth, the covariation data in the present study were presented simultaneously in the form of scatterplots, rather than sequentially. This procedure has the methodological benefit of allowing subjects to make numerous judgments in a single session and of improving the judgments' sensitivity to the data by reducing processing demands on memory. Finally, the use of scatterplots renders the task similar to the tasks faced by actual scientists in that such plots summarize data acquired over time into a single display having a conventional format.[2]

[2]Two readers of prepublication drafts of this article commented that, in actual practice, scientists would not gauge statistical relationships from graphs without recourse to numerical correlation coefficients. But scientists, especially those among the growing ranks who practice exploratory data analysis (Tukey, 1977), do in fact commonly examine statistical relationships by viewing scatterplots independently of numerical correlation coefficients (for discussion of the scatterplot matrices used in such visual analyses, see Cleveland, 1994, pp. 193–209). The perils of relying on numerical measures of covariation without visual inspection of scatterplots are vividly demonstrated in Anscombe's (1973) classic essay on the necessity of graphing data.

It was hypothesized for our study that estimates of covariation would depend on the degree to which subjects could rely on their theoretical intuitions, specifically that data-based estimates would be drawn in the direction of subjects' prior theories, and that this effect would be greater when the variable names were given in advance than when they were given simultaneously with the data. In the present context, the theory-dependency of observation would be demonstrated to the degree that our subjects' assessments of the scatterplots are altered by the presence of their implicit personality theories. If theories actually free perceivers from the constraints imposed by the data, as suggested by Jennings et al. (1982), then no differences should be observed between judgments in the theory-only condition and the theory-plus-data condition. If, on the other hand, theory-based covariation assessment reflects an interaction of prior theories and available data, as postulated by Alloy and Tabachnik (1984), then judgments made when both theory and data are present should reflect a compromise between the two. However, because theories are assumed to influence the process of observation only when their mental representations are activated, the effect of prior theory on data assessment is expected to occur only when the perceivers are primed in advance on each trial to think about the relationship between trait pairs.

Method

Subjects. A total of 82 male and female students enrolled in introductory psychology classes at the University of Maine served as subjects. All subjects received course credit for participation in the study.

Stimulus materials. Because scientists typically make their observations under the guidance of theory in a setting that is familiar and well-structured, an effort was made to provide participants in the present study with a maximally familiar context in which they could exercise their prior theories. Accordingly, scatterplots for the present study were based on data generated by a previous sample of 67 subjects drawn from the same pool. These subjects rated themselves on each of 45 personality traits using a 100-point rating scale. Pearson product-moment correlation coefficients between pairs of traits were then calculated and scatterplots were produced by the SPSS-X scatterplot program (SPSS Inc., 1983). Before the axis labels were added, all extraneous information was removed from the scatterplots, leaving only the scale markings and data points. Whenever two or more data points fell at the same place on a plot, the data points were randomly distributed around the immediately adjacent area. Scatterplots showing obvious nonlinear trends in the data or obvious violations of homoscedasticity of variance were eliminated from the pool. In order to vary correlations beyond the range typically used in previous research, plots were then chosen in which the displayed correlations fell into three categorical ranges: positive correlations (+.25 to +.56), zero correlations (–.10 to +.10), and negative correlations (–.25 to –.45). For the stimuli chosen, all correlations in the positive and negative categories were statistically significant. The use of non-zero correlations having intermediate magnitudes was suggested by earlier findings of high variability in judgments of correlations in the range of r = .25 to .60 (e.g., Jennings et al., 1982), with the assumption that highly variable judgments would be more likely to be sensitive to the effects of prior theoretical intuitions. Examples of the chosen trait pairs and their correlations are: Cooperativeness and Thoughtfulness (r = +.50); Morality and Musical Ability (r = .00); and Timidness and Persistence (r = –.31).

Design. In order to separate out the effects of data and theory on perceived covariation and to assess their effect in combination, participants were divided into four approximately equal groups of about 20 people. The four groups were as follows. (a) *Data-Only:* Participants were presented with scatterplots on which the axes were simply labeled X and Y and no information about the nature of the variables was provided; the scatterplots thus depicted the self-report data from the prior sample of subjects, as described above, but without the variables identified. (b) *Theory+Data:* Participants were presented with the same scatterplots as in the Data-Only condition but with the axes labeled with the names of the personality traits. (c) *Theory+Data-Primed:* This group received the same scatterplots as the Theory+Data group except that 30 seconds prior to the presentation of each scatterplot the subjects were given the names of the traits to be shown and were instructed to think about the relationship between the traits. (d) *Theory-Only:* In this condition, only the names of the traits were provided and no scatterplots were presented; participants were asked to estimate the degree of relationship in the same pairs of traits as in the scatterplot conditions, using the same rating scale.

The various scatterplots shown to subjects were chosen so as to reflect the wide range of covariation that perceivers might ordinarily encounter. Each subject rated scatterplots depicting three types of covariation — positive, negative, and zero — or, in the case of Theory-Only subjects, rated the trait pairs having those same positive, negative, and zero correlations. The three types of correlations were intermixed and presented in random order. This resulted in a 3 X 4 (Type of Correlation X Group) factorial design, with type of correlation as a within-subjects factor.

Procedure. Subjects were tested in groups of 10 to 12. They were seated at desks and given individual rating sheets for their responses. The experimenter informed the subjects that the study would examine their ability to estimate the degree of relationship between pairs of variables. The concept of correlation was explained and examples of positive, zero, and negative correlations were presented. These examples were given in scatterplot form to subjects in the conditions where scatterplots were used as stimuli, and in written form to subjects in the Theory-Only condition. Scatterplots were presented on an overhead projector in a dimly lit room. Each scatterplot was presented for 30 seconds and the subjects in the three scatterplot conditions were shown 36 correlations (12 positive, 12 zero, and 12 negative) in random order. The magnitude of covariation was judged on a 201-point rating scale, with values ranging from −100 to +100 and zero representing no relationship. All participants recorded their judgments on rating sheets. Subjects in the three scatterplot conditions wrote their judgments next to numbers that were keyed to the scatterplots, and subjects in the Theory-Only condition wrote them next to pairs of trait names that were listed on their rating sheets.

Results

The intent of the study was to investigate whether perceived correlations would depend on the degree of subjects' reliance on their theories, whether this dependency would require a priming interval for the activation of theory-based expectancies, and whether any tendency for theories to produce heightened covariation estimates would be moderated by the availability of data. These issues are addressed by the results shown in Figure 1, which portrays the mean ratings of perceived covariation in the four conditions. A 3 X 4 (Type of Correlation X Group) analysis of variance was computed on the mean ratings of each subject. The main effect of the Type of Correlation was significant, $F(2, 156) = 551.16$, $p < .001$, indicating that participants could differentiate between scatterplots portraying positive, zero, and negative correlations. The main effect of Group did not reach significance; as Figure 1 suggests, this was a consequence of the fact that the differences in the means of the positive and negative correlations were symmetrical, thus eliminating any overall group effect. Of greater interest is the finding of a significant Correlation Type X Group interaction, $F(6, 156) = 32.76$, $p < .001$, revealing that the perceived magnitude of covariation was greater in the conditions in which subjects relied on their theoretical intuitions. An analysis of the simple main effect of Group for each type of correlation showed that the group effect was significant for positive correlations, $F(3, 78) = 13.26$, $p < .001$; zero correlations, $F(3, 78) = 2.88$, $p < .05$; and negative correlations, $F(3, 78) = 39.21$, $p < .001$. This analysis indicated that for all three correlation types the magnitude of perceived covariation increased the more the subjects relied on their theoretical intuitions.

More detailed scrutiny of the effects of theory and theory-priming on data observation was achieved by conducting post-*F* comparisons of individual conditions. A Newman–Keuls analysis of the differences among the means of

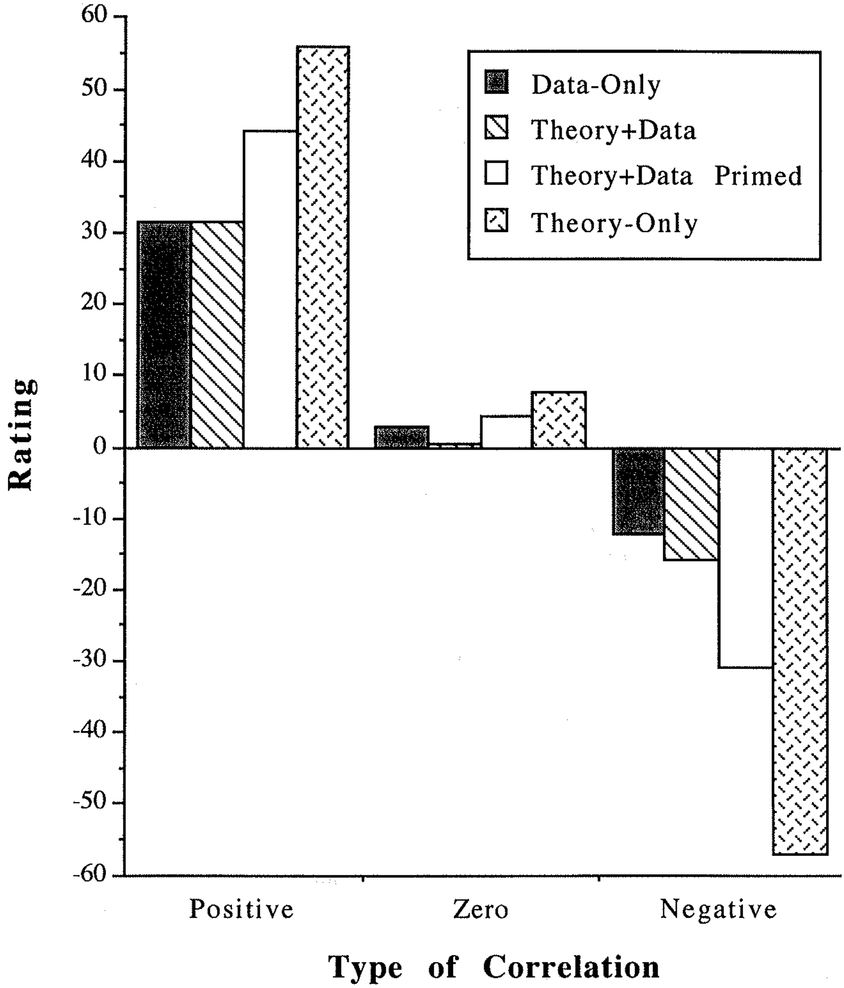

Figure 1: Mean covariation assessment ratings for the four conditions and three ranges of correlation.

the various groups showed that, for both positive and negative correlations, estimates of the Theory-Only group ($M = 55.96$; $M = -56.96$) were significantly greater in magnitude ($ps < .05$) than the estimates in each of the other three conditions. In addition, the covariation estimates of the Theory+Data-

Primed group (M = 44.25; M = –30.88) were significantly greater in magnitude ($p < .05$) than those of either the Data-Only (M = 31.57; M = –12.17) or Theory+Data group (M = 31.49; M = –15.85). However, the differences between the Data-Only estimates and Theory+Data estimates were not significant. Finally, for the zero-correlation condition, the differences among the means did not reach statistical significance.

The relative contributions of subjects' prior theories and the available data can be determined by comparing the means in the Theory+Data conditions to the means for the Data-Only and Theory-Only conditions. Because the means in the Theory+Data condition were not significantly different from the Data-Only condition, it can be concluded that in the absence of time to think about the relations, subjects' judgments were determined almost exclusively by the available data. In the Theory+Data-Primed condition, the mean for the positive correlation condition (M = 44.25) was about halfway between the means of the Data-Only and Theory-Only conditions (i.e., 43.77). For the negative correlation condition, the mean for the Theory+Data-Primed condition (M = –30.88) was slightly greater than the halfway point (i.e., –34.57). Thus, in the Theory+Data-Primed condition, judgments were influenced approximately equally by the data and theory.

Participants were asked to give their covariation ratings on a subjective 201-point scale, rather than in terms of estimated Pearson correlation coefficients, in order to keep the task intuitive and to prevent subjects from being distracted by the technicalities of statistics with which they were marginally familiar. One consequence of using the subjective scale is that the results do not bear directly on the issue of the accuracy of their estimates (see Lane et al., 1985). However, a high correlation between the actual correlation and perceived covariation estimates for all the groups (Data-Only, $r = .91$, $p < .05$; Theory+Data, $r = .92$, $p < .05$; Theory+Data-Primed, $r = .93$, $p < .05$) provides further support for the idea that subjects were sensitive to the actual covariation and were not simply making categorical judgments of whether the scatterplots were positive, negative, or zero.

Discussion

Consistent with the model of covariation assessment proposed by Alloy and Tabachnik (1984), the results of the present study indicate that covariation estimates are influenced both by data and by perceivers' prior theoretical intuitions. Confirming Schneider's (1973) claim that people hold strong intuitive theories about relationships between personality traits, our subjects who received no data gauged intertrait correlations to be very high. More generally, the finding that theory-based estimates are less conservative than data-based estimates accords well with other previous findings (Jennings et al., 1982; Trolier and Hamilton, 1986; Wright and Murphy, 1984). In line with our predictions and with previous results (Trolier and Hamilton, 1986; Wright and Murphy, 1984), those participants to whom both data and theory were available perceived a greater magnitude of covariation when they had access to their prior theories than when they relied only on the available data. The fact that data-based estimates were pulled in the direction of prior theoretical beliefs also confirms Hanson's (1958) thesis of the theory-ladenness of observation, and demonstrates that such a phenomenon can occur with relatively unambiguous data displays of the sort used by practicing scientists, as well as with the Gestalt-like examples found in the philosophical literature. In addition, it shows that observation of data can be colored by naturally occurring, preexisting theories, as claimed by Hanson, as well as by theories instilled through direct laboratory manipulations (Trolier and Hamilton, 1986; Wright and Murphy, 1984).

Even though some earlier work (e.g., Jennings et al., 1982) has found subjects' theory-based judgments to be unsystematic and related only loosely to actual covariation, participants in the present study showed no such tendencies. The covariation represented in the scatterplot data was found to influence judgments both in the presence of theoretical beliefs and in their absence. In the theory-based conditions, a strong relationship between the actual and perceived covariation was observed. Thus, the presence of prior theories did not reduce our subjects' sensitivity to the relations in the data. Moreover, our pilot data and the findings of Billman et al. (1992) indicate that when given data inconsistent with prior theories, subjects do not reverse the direction of their judgments in favor of their prior theories. These findings, taken together with the fact that exposure to data did moderate the magnitude of theory-based judgments in the present study, demonstrate that exposure to data does constrain people's theory-based observations. Thus, the suggestion of Jennings et al. (1982) that prior theories may free perceivers from the constraints imposed by the data was not supported in this study.

An important issue raised by the present study concerns the cognitive mechanisms by which theories affect the processing of the available data. Jennings et al. (1982) suggested that theory-based judgments often depend on the use of a representativeness heuristic, whereby subjects rely on a few exemplary cases that have been stored in memory in making their judgments (Kahneman and Tversky, 1972). Although the present findings cannot refute this explanation, an account in terms of representativeness does not adequately explain how the supposedly representative cases are combined with the available data. Instead, it is likely that subjects' prior theories may lead to a selective encoding of the covariation information in the scatterplots. Alloy and Tabachnik (1984) have suggested that prior theories may lead subjects to focus on confirming cases. Similarly, Wright and Murphy (1984) have argued that subjects making theory-based assessments of data attend less to error variance and atypical cases such as outliers. In studies of both untrained subjects (Jennings et al., 1982) and statistically trained subjects (Bobko and Karren, 1979; Cleveland et al., 1982), perceived covariation in actual data has been found to be a positively accelerated, rather than a linear, function of the Pearson correlation coefficient, with covariation estimates remaining fairly low until the Pearson *r* reaches about .60. Consequently, data-based judgments of correlations in the low to medium range, as used in the present study, would appear to reliably underrepresent the actual covariation. It is therefore likely that the difference between data-only and theory-based judgments in our study was enhanced by the theory-based tendency to perceive strong associations in the scatterplot data. However, further research is needed to determine how theories specifically influence the processing of scatterplots.

As suggested earlier, the fact that judgments of covariation in the present study were influenced by subjects' prior theories can be viewed as support for the claim of Hanson (1958) and Kuhn (1962) that scientific theories exert a pervasive influence on the processing of empirical data. This support for the thesis of theory-ladenness gains added credibility from the present study's use of realistic scatterplots as stimuli and from the use of a subject matter about which the subjects, like their scientific counterparts, have strongly held preexisting theories that they bring to bear on the process of observation. Moreover, these findings provide even stronger support for Hanson's thesis than the Gestalt-like perceptual examples that Hanson and others provide because our stimuli consisted of relatively unambiguous quantitative data.

A crucial finding of the present study is that, when compared to estimates in the Theory-Only condition, subjects' estimates in the Theory+Data-Primed condition were moderated by exposure to the scatterplot data. This result undermines the view of positivist philosophers that the testing of theories against data that are theory-laden is impossible. On the contrary, it appears that observations that are colored by theoretical presuppositions can and do result in the modification of the very presuppositions that shape them.[3] This is a conclusion that, despite running counter to positivist claims, would be expected on the basis of psychological models (e.g., McClelland and Rumelhart, 1981) that recognize the complementary roles of top-down and bottom-up processes in observation. It is also a conclusion that would be

[3]To acknowledge that theories can be tested with theory-laden data is not, however, to suggest that the theory-ladenness of observation is altogether unproblematic for the conduct of science. Still to be taken seriously is the possibility that data can be so theory-laden in some cases as to provide only weak or inefficient tests of the theory. This could happen, for example, in situations where scientists actively select and attend to only those data that confirm their theories while neglecting disconfirmatory data. On the potential dangers of confirmation bias, see Greenwald, Pratkanis, Leippe, and Baumgardner (1986) and Tweney et al. (1980).

embraced by the growing number of postpositivist philosophers of science who have already recognized the capacity of theory-laden data to occasion modifications in theoretical beliefs. Just as Alloy and Tabachnik (1984) have portrayed judgments of covariation as resulting from the interaction of data and prior beliefs, these philosophers — most notably Laudan (1977) and Brown (1977) — have come to view scientific decision-making as an ongoing process of belief adjustment based on an interplay between empirical data that are construed with the aid of theories and theories that are tested by reference to those theory-laden data. It is important to note that the conclusion of these philosophers that theories can be tested with theory-laden data is based on extensive evidence from the history of science, that is, from numerous case studies of scientific practice in which such a process occurred (see also Donovan, Laudan, and Laudan, 1988). The present study may thus be viewed as complementing and reinforcing the (essentially empiricial) conclusions of historically oriented philosophers of science. Pending the outcome of further laboratory analyses of theory-laden observation, it may even be reasonable to view the present study as an experimental demonstration of the sort of psychological processes that underlie those historical generalizations.

The degree to which the results of analogue studies such as the present one are truly relevant to understanding scientific judgments remains, of course, an open issue. The most obvious disanalogy in the present case is that our study employed relatively naive subjects who had little scientific training or experience making judgments about scatterplots, whereas Hanson's (1958) concern was with how trained scientists perceive data as a function of their varying theoretical beliefs. Yet the existing studies that compare the performance of laypersons and scientists on scientific reasoning and data-interpretation tasks have often found no superiority for the scientists (for reviews, see Faust, 1984, and Mahoney, 1976). For example, Mahoney and DeMonbreun (1978) found that neither trained physicists nor Ph.D. psychologists were less likely than a group of nonscientists to engage in confirmation bias in a scientific inference task, and that the nonscientists were actually less prone to premature speculation on hypotheses early in the data-collection process (for case histories of confirmation bias in trained scientists, see Brush, 1974, and Mitroff, 1974). Thus, the drawing of conclusions about the theory-ladenness of scientific observation from research on the effects of intuitive theories on nonscientists' observations is by no means implausible. We share the view of a growing consensus that psychological methodology is sufficiently well-developed to provide insights into the practice of science (Fuller, 1988; Giere, 1988; Goldman, 1986; Gorman, 1992; Neimeyer, Shadish, Freedman, Gholson, and Houts, 1989) and we believe that generalizations from experimental research to science are warranted by the degree to which the research captures the same psychological processes employed in science. As just noted, the convergence of our results with the historically based conclusions of postpositivist philosophers such as Laudan (1977) and Brown (1977) provide grounds for optimism in this regard.

Several other observations about the present results are worth making. One noteworthy finding from the present study is the dependency of the theory-ladenness phenomenon on a priming interval. The effects of priming found here imply that the interaction of theory and data is not a purely perceptual phenomenon; if it were, the two groups in our study that were exposed to both data and theory would presumably have shown an equal susceptibility to the influence of their theoretical intuitions. Thus, the fact that the mere presence of theoretical information in the Theory+Data condition did not lead to a significant increase in the perceived covariation above that found in the Data-Only condition suggests that time is needed for perceivers to retrieve their theoretical beliefs from memory in order for them to have an impact on judgments. Theory-based influences on covariation assessment would thus appear not to be an automatic process (see Schneider and Shiffrin, 1977). The apparent involvement of nonperceptual factors in the observed priming effect means that our results cannot readily be explained by McArthur's (1980) hypothesis that phenomena such as illusory correlation are due to the perceptual system's being "attuned to pick up certain co-occurrences more readily than others" (p. 515; see also McArthur and Baron, 1983). Rather, in agreement with the results of Billman et al. (1992), our findings support the conclusion that prior theories influence the assessment of covariation at a non-sensory stage of the judgment process. Future research might explore the time interval needed to maximize the effects of theory priming. Some critical duration may be found between the time of priming and the use of theoretical intuitions. Nevertheless, as De Mey (1980) has suggested, "perceptual entities can penetrate conceptual pyramids at many levels" (p. 19), and the interplay of perceptual and conceptual factors in theory-laden perception is no doubt complex.

An alternative to the retrieval-time explanation offered above is that the major difference between the Theory+Data and Theory+Data-Primed conditions lies in how they make theory and data differentially salient. In the Theory+Data condition, subjects' attention may be drawn to the presence of scatterplot information so that they focus on the data and consequently give little consideration to their prior theories; in other words, the subjects become primarily data-driven because the scatterplots are the most conspicuous source of information. In the Theory+Data-Primed condition, subjects have considered the relations between the trait pairs prior to the presentation of the scatterplots so that their theoretical intuitions have some salience at the time the graphs are presented; as a result, subjects in this condition may give their prior theories and the scatterplot data relatively equal weight when making their assessments of covariation. The retrieval-time and relative-salience explanations are not mutually incompatible and both processes may be operating in theory-based covariation assessment. What is clear from the present results, however, is that the observed effect of theory on observation, whether due to relative salience or retrieval lag, is time-dependent; and it is relevant to note that salience (unlike retrieval or cognitive activation) is not usually considered to be a time-dependent process.

In contrast to what has been observed in some previous research (Erlick, 1966; Erlick and Mills, 1967; Peterson, 1980), subjects in the present study had little difficulty detecting negative covariation, perhaps in part because the information was presented in scatterplot form. Previous findings have been explained by suggesting that the concept of negative correlation is not a part of perceivers' statistical intuitions. It is also noteworthy that the effects of theory on judgments of scatterplot data were found to be the same for negative relationships as for positive ones; in the case of negative covariation, subjects adjusted their estimates in the direction of their prior theories in a manner exactly symmetrical with their adjustments in cases of positive covariation. Thus, it can be concluded that our subjects, like trained scientists, understood the concept of a negative relationship and that they applied this understanding in forming their theory-based judgments.

In conclusion, the results of the present experiment show that the perception of covariation between variables is influenced jointly by objective relations in the data and by perceivers' prior theories. Although no extant theoretical account provides a complete picture of the actual processes by which perceivers access their prior theories and combine them with new observations, the use of scatterplot stimuli as a means of presenting data on which covariation judgments can be based provides a promising avenue for the further study of such processes, especially in the context of scientific and technical decision making where observers are confronted with complex arrays of information. Finally, although some authors (De Mey, 1980; Feigl, 1970) have questioned how theories can be modified by data if observation is theory-laden, none of the present findings indicates that the phenomenon of theory-based observation would immunize scientists from theory-disconfirming data. Thus, the findings give no grounds for concluding that observation is necessarily rendered subjective or arbitrary in any damaging sense by its theory-laden nature. They do suggest, however, that the positivists' dichotomous view of observation as being either impeccably pure or else dangerously contaminated with theory is overdrawn and untenable.

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