Psychological Review
1987, Vol. 94, No. 2, 277–280

0033-295X/87/$00.75

THEORETICAL NOTE

More on the Speed and Accuracy of Positive and Negative Responses

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The account given by the diffusion model (Ratcliff, 1985) of the relation between positive and negative responses has been criticized by Proctor, who argues that the diffusion model provides no theory of criterion setting and that it violates psychophysical principles. In reply, I argue that psychophysical principles are not violated and that a quantitative theory of criterion placement is currently outside the scope of the diffusion model and many other models of memory. I point out that the strength of the diffusion model lies in its ability to account for aspects of the data other than just mean reaction time (RT), and in its generality across experimental paradigms.

Within the framework of the diffusion retrieval/decision model, Ratcliff (1985) provided an interpretation of the fast-*same* effect in a sequential matching task. The sequential matching task requires the subject to judge whether two letter strings are identical or not, and the fast-*same* effect refers to the result that often *same* responses are faster than *different* responses. The diffusion model was fitted to data from three experiments (Proctor & Rao, 1983; Proctor, Rao, & Hurst, 1984; Ratcliff & Hacker, 1981), and the fast-*same* results (as well as a fast-*different* result) were fitted without assuming different processing stages for positive and negative comparisons (c.f., Bamber, 1969; Proctor, 1981). The diffusion model also provides more than an interpretation of a single phenomenon, the fast-*same* effect. It provides an explanation of the relation among accuracy, reaction time (RT), and the shape of the RT distribution, at a quantitative level across a range of experimental paradigms (see Ratcliff, 1978, for four types of recognition memory procedures; Ratcliff & McKoon, 1982, for semantic memory procedures; and Ratcliff, 1981, for matching paradigms). In addition, the model provides an account of the growth of accuracy as a function of time in response signal procedures (Ratcliff, 1978, 1981) and recently has accounted for the behavior of the accuracy of guesses produced prior to the comparison process reaching a decision (Meyer, Irwin, Osman, & Kounios, 1986; Ratcliff, in press). These latter cases provide strong tests of the model because the model is constrained by a small number of free parameters; in both cases, the predictions of the model are in good agreement with the experimental data. The diffusion model should also be understood in a wider context as an exemplar of a class of sequential sampling models that deal with a range of other phenomena (e.g., Laming, 1968, 1979; Link, 1975, Link & Heath, 1975; Vickers, 1979).

Within the framework of the diffusion model, the fast-*same* effect in matching is modeled in the same way that fast positive responses in recognition memory paradigms are modeled. Fast-*different* responses (Ratcliff, 1981; Ratcliff & Hacker, 1981) and fast negative responses in recognition memory (Atkinson & Juola, 1973) are modeled in similar ways. Thus, for positive and negative responses, the diffusion model provides a consistent set of parameter estimates, and these estimates can form the basis for hypotheses about the factors that control criterion settings. It should be stressed that the model makes no assumptions about qualitatively different processing for positive and negative comparisons and obtains a fast-*same* effect only by settings of the parameters (drift criterion and diffusion process boundaries) of the model.

Proctor (1986) has criticized this account in four main ways: First, he argues that it is necessary to assume a complex pattern of criterion settings to produce fits to the data, and no rationale is provided to explain why these patterns of settings occur; thus he labels the account "implausible." Second, he claims that fits of the model violate accepted psychophysical principles. Third, he argues that the drift criterion that governs the relative rate of accumulation of positive compared to negative evidence should not be viewed as a response criterion and that interpretations of the fast-*same* effect solely in terms of response criteria are invalid. Fourth, he argues that the account given by Ratcliff (1985) is incomplete because it fails to account for differences between sequential and simultaneous matching.

Although Proctor is correct concerning the lack of a theory for criterion settings, the criticism indicates that the theory is incomplete, not implausible. This limitation is not peculiar to the diffusion or other sequential sampling models. There are few accepted psychological theories of criterion placement even in the most popular decision theory, signal detection theory. For example, Laming (1973, p. 75) notes that the location of the criterion in signal detection is assumed to be influenced by the

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This work was supported by Grant BNS-8510361 from the National Science Foundation and Grant HD-18812 from the National Institute of Child Health and Human Development. I would like to thank Jerry Busemeyer, Reid Hastie, Duncan Luce, an anonymous reviewer, and Gail McKoon for their suggestions and comments on this note.

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relative probability of a signal, by the rewards and costs associated with the decision outcomes, and by the motivational state of the subject. This latter factor would seem to require a theory of motivation. There has been research on modeling subjects' adjustments of the criterion in signal detection and much of this work was focused on trial-to-trial fluctuation, not initial settings (e.g., Laming, 1973, chap. 5; Thomas, 1973; Triesman & Williams, 1984). When absolute settings have been examined, results have been inconclusive. For example, Dusoir (1975) examined three classes of hypotheses about the form of isobias curves and concluded that none of the hypotheses were adequately supported by experimental data (see also Healy & Kubovy, 1977, and Murdock, 1974, for application to recognition memory). These examples do not mean that signal detection is implausible (as Proctor argues about the diffusion process), only that the theory is incomplete.

Laming (1979) examined three of the more straightforward hypotheses (two proposed by Link, 1975) about criterion settings in both his version of the random-walk model and that of Link and Heath (1975). The starting point of the walk could be chosen to minimize the total number of errors, to match the probability of the two choices, or minimize the mean RT subject to some error rate. On the basis of analyses of several experiments, he concluded that none of the hypotheses were capable of dealing with all the results from the experiments considered.

The situation is not different for recent models in cognition. Some of the more popular models in cognition also lack a model of criterion placement (e.g., Gillund & Shiffrin, 1984; Hintzman, 1986; Link & Heath, 1975; McClelland, 1979; McClelland & Rumelhart, 1981; Murdock, 1982) and so lack completeness in the same way as the diffusion model.

Empirical work aimed at investigating criterion placement in sequential sampling models supports the argument that subjects use prior knowledge to set their criteria. There are two studies that have implications for this discussion, the first empirical and the second theoretical. Busemeyer (1985) performed an experiment in which subjects were to learn optimal criterion settings in a simple sequential task (subjects repeatedly obtained data samples and were allowed to stop sampling and respond when they believed they had enough information, i.e., the stopping rule was modeled by the decision rule of a random walk). The data showed that optimal criteria were reached only after several sessions of practice, over 100 trials. In a theoretical study, Busemeyer and Townsend (1985) examined the use of payoffs or prior probabilities to determine criterion placement in a signal-detection model. Their study showed the same pattern: The model took a large number of trials, over 100, to reach asymptotic performance (even then, the asymptote reached was not optimal). In Proctor and colleagues' studies, only 100 trials are presented per condition. Thus subjects must be using prior experience to reach stable performance. In addition, subjects were instructed to make use of probability information at the beginning of each block of trials, essentially an explicit instruction to use past experience. Collectively, these examples show that it is necessary to model the past history of a subject to account for criterion placement, and I argue that this is a difficult task and one that is outside the scope of, yet is an important challenge to, current theory. However, some progress can be made (see below) in relating the patterns of criteria settings obtained by Ratcliff (1985) to theoretical proposals that view criterion settings in terms of adaptation levels (Broadbent, 1971; Warren, 1985).

The second point made by Proctor is that the diffusion model violates a principal of signal-detection theory, namely that changes in instructions affect sensitivity and not bias, as the theory predicts. This violation occurred in one experiment fitted by Ratcliff (1985; Ratcliff & Hacker, 1981, Experiment 1). However, Ratcliff (1985) noted that the violation was not only in the theory, but also in the data. In this case the theory followed the data, and it is the violation in the experiment that deserves primary attention, not the theory.

With this violation as an example, Proctor argues that the diffusion model is too flexible, that it can generate any pattern of *same* and *different* mean RTs and errors. Ratcliff (1985) noted that this was true (perhaps within some limits) with respect to the speed and accuracy of *same* and *different* responses, but viewed this flexibility as a positive aspect of the model because subjects are capable (with appropriate payoffs) of adopting a wide range of accuracy and RT combinations. However, along with this flexibility for RTs and error rates, the model must at the same time be constrained to account for the relationship between accuracy and RT distributions. Thus, the model has both the flexibility to cover a range of data and an internal structure that predicts constrained relation among various other aspects of data.

The third point made by Proctor is that the fast-*same* effect is only obtained in the diffusion model by complex patterns of settings of three criteria: two that represent response boundaries and one (the drift criterion) that is equivalent to the criterion in signal-detection theory. Proctor states that Ratcliff and Hacker (1981, 1982) claimed the fast-*same* effect could be explained in terms of setting only response criteria. However, Ratcliff and Hacker discussed only criteria, explicitly noting all three criteria used by the diffusion model (Ratcliff & Hacker, 1982). Nowhere did they suggest that the effect could be explained solely in terms of settings of the response criteria in the diffusion model. (Note that the drift criterion is rarely set symmetrically in any fits to data.)

A fourth point made by Proctor is that Ratcliff (1985) failed to specify the combinations of criteria settings that give rise to the larger fast-*same* effect with simultaneous presentation than with sequential presentation. Ratcliff argued that the simultaneous case could involve multiple comparisons especially when multiletter strings serve as the stimuli (evidence for this included very slow RTs for multiletter matching). In response to Proctor's request for an explanation, I performed fits to the single-letter matching data from Proctor and Rao (1983) and found similar fits to those shown in Table 3 (Ratcliff, 1985, p. 223). The main differences were a larger change in the comparison criterion and a more moderate change in the starting point of the diffusion process. The theoretical reason for a smaller fast-*same* effect in the data was a greater separation between the starting point and the *same* boundary in the simultaneous case, compared to the sequential case, leading to longer RTs.

It is important to note that a larger fast-*same* effect in sequential matching is not always found (see Krueger, 1983). Thus any complete account has to explain why this effect is found in some experiments and not in others.

Proctor makes several factual errors and serious omissions. First, Ratcliff and Hacker (1981, 1982) did not argue that adjustments in response criteria alone were sufficient to account for changes in bias; they used the more neutral term *criteria* to also include the drift-rate criterion. Thus Proctor's section "Sufficiency of Response Criteria" (1986, p. 473) misstates Ratcliff and Hacker's position. Second, the diffusion model was able to account for the fast-*different* effect obtained when difficult negatives are used in an experiment. Proctor ignores the existence of fast-*different* conditions in his analyses (see similar effects in recognition memory data, Atkinson & Juola, 1973). Third, Proctor states that the models of Ratcliff (1978) and Link (1975) require that the drift criterion be fixed as a function of yes–no bias. However, in general, the sequential sampling models allow this criterion to be adjustable; for example, Link and Heath (1975, p. 78) term this criterion "the referent" and it is "shaped or emphasized by the number of previous exposures to each stimulus" (see also Ratcliff, 1978, 1985; Vickers, 1979). Fourth, Proctor states that the primary effect of instructions (in Ratcliff & Hacker, 1981, Experiment 1) was on response boundaries; in fact, the primary effect was on the drift criterion (30% change) with a secondary effect on response boundaries (20% change). Fifth, Proctor concludes that the account of the fast-*same* effect provided by the diffusion model is not sufficient. Ratcliff's fits of the diffusion model are sufficient; Proctor probably means that the account provided by Ratcliff is not satisfactory by his criteria.

Ratcliff (1985) discussed generalizations about criteria settings and argued that the results of the fits to the data provided a consistent pattern of criteria settings. It is possible to form some hypotheses about the factors that might influence the two kinds of criteria (boundary positions and zero point of drift, i.e., goodness-of-match). The boundary positions are set as noted in Ratcliff (1985) so that the more difficult decisions are well discriminated. For example, when there are difficult negatives (e.g., Ratcliff, 1981; Ratcliff & Hacker, 1981), the starting point will be set further away from the *same* boundary to minimize the number of false-*same* responses. If there are easy negatives, then positive responses will be more difficult (because any discrepancy will be evidence for a *different* decision) and the *same* boundary will be set further from the starting point.

It is assumed that boundary settings as well as the zero point in goodness-of-match (drift rate) are under the control of subjects. Once the boundary positions are set, the criterion in drift is adjusted to roughly equate some function of accuracy and RT (e.g., Laming, 1979). For example, the results in Proctor and Rao (1983) show very approximate probability matching in error rates (see Healy & Kubovy, 1981; Thomas, 1975; Thomas & Legge, 1970) so that the proportion of errors tracks the probability of *same* and *different* test trials. Because the criterion in the drift rate is the only criterion that changes systematically across the fits to probability conditions, it might be thought to act as an adaptation level (e.g., Broadbent, 1971, chap. 6; Link & Heath, 1975; Warren, 1985; see also Vickers & Leary, 1983, for contrasting effects) that is used by the subject to adjust performance when the boundary positions have been set. The setting of the drift criterion may then be controlled within an experiment so that it automatically tracks changes in factors such as stimulus probabilities and payoffs. However, if the experimental manipulations are large, the subject may alter boundary position criteria as well, as in the fits to Ratcliff and Hacker's (1981) instruction manipulations.

Proctor (1986) has chosen to focus on the fast-*same* effect and argues that any explanation that does not give "a plausible, logically coherent account" (p. 474) is inadequate. I argue that the diffusion model provides an adequate account of the fast-*same* effect (note the discussion of criterion setting in Ratcliff, 1985) and, in addition, provides a logically coherent account of accuracy, RT distributions, and growth of accuracy as a function of time. The models that propose separate processes for *same* and *different* responses (see, for example, Bamber, 1969; Proctor, 1981) provide an account of mean RT but are mute on the behavior of accuracy, bias, and conditions in which a fast-*different* effect is found, and so are clearly less complete than the diffusion retrieval/decision model in Ratcliff (1985).

To summarize, the points made by Proctor (1986) do not call into question the explanation of the fast-*same* effect proposed by Ratcliff (1985) and Ratcliff and Hacker (1981, 1982) or the adequacy of the fits presented in Ratcliff (1985). Proctor does correctly remind us that the determinants of criterion settings in the RT domain are complicated. However, the diffusion model does allow some tentative hypotheses to be formulated that begin to address the concerns raised by Proctor.

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Received March 19, 1986
Revision received August 6, 1986 ■

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A special issue of the *Journal of Abnormal Psychology* is being planned that will comprise both empirical research and review papers relevant to major models or conceptualizations of addiction. Solicited manuscripts should review empirical literatures, advance theory, or present major empirical data sets relevant to models or theories of addiction; namely, Pavlovian, opponent-process, operant, genetic, incentive, biopharmacological, social learning, stress/coping models, and so on. Manuscripts that have clear relevance to motivational processes in addiction are especially welcome. Thus, papers that address specific addiction phenomena (e.g., dispositional tolerance) should make clear the relevance of such phenomena to addiction theory and drug motivation.

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