Response Strength and the Concept of the Repertoire

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The concept of response probability is central to the task of predicting behavior, whereas the closely related concept of response strength is commonly applied to ongoing overt or covert behavior, as indexed by a variety of typically correlated measures. Consideration of certain behavioral phenomena suggests that the latter concept applies equally to latent behavior. The apparent unity of emitted behavior masks a bedlam of concurrent fluctuations in strength of responses in the repertoire but below the threshold of emission. In problem solving and recall tasks, latent target responses are differentially strengthened by successive probe stimuli until such responses become stronger than myriad competing responses. It appears then that an understanding of seemingly elementary cognitive phenomena requires a consideration of the dynamics of latent responses in the repertoire. Some speculations are advanced about how the strongest of various latent responses can be emitted without blending with competing responses.

Keywords: Inhibition, N400 component, repertoire, response competition, response latency, response probability, response strength, semantic priming.

The shouting of the football fan at the game-saving goal will be immediate, loud, repetitive, persistent, and will crowd out any tendency to comment on the weather. That is to say, behavior tends to hang together in its latency, intensity, frequency, resistance to extinction, and tendency to occur in competition with other responses. These response measures can sometimes be differentiated by conflicting contingencies: For example, we usually punish people for repeating themselves excessively, so rate of response is not always a reliable indicator of other measures of verbal responses, but the effect of a naïve audience is usually conspicuous. Likewise, a high frequency, short latency response might be uttered at low intensity in the presence of a sleeping baby, a grouchy librarian, or a crowded restaurant, ill-bred cell phone users notwithstanding. However, the exceptions prove the rule: All other things being equal, the measures tend to vary together. When we are simply bursting to say something, we may blurt it out quickly and forcefully; we may repeat it at every opportunity; we may continue to insist on our point, even if not reinforced or actively punished; and our response may preempt other behavior that would normally be occurring at the time, as when we rudely interrupt another speaker instead of patiently waiting our turn. Because of this typical covariation of measures, we find it helpful to use a unifying term. In behavior analysis we speak of response *probability* or response *strength*.

In Skinner's *William James Lectures*, a precursor to the book *Verbal Behavior* (1957), he introduced the concept with these words:

> Our basic datum is not a verbal response as such but the probability that a response will be emitted. We recognize that some responses are more likely to occur than others and that, in fact, every response may be conceived of as having at any moment an assignable probability of emission. *A latent response with a certain probability of emission is not directly observed. It is a scientific construct. But it can be given a respectable status, and it enormously increases our analytical power.* (Emphasis added.)

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When behavior has actually been emitted and observed, it makes no sense to speak of its *probability,* but the term *strength* is not similarly restricted: An emitted response may be tentative and weak, or rushed and loud, and we should like to differentiate these cases. Even so, if some or all of the various response measures can be evaluated directly, even this term loses its force. Rather than speaking about a high strength response, we are more likely to say that the person is being loud, or that he never shuts up about his kids, or that he is talking too fast. But the terms *probability* and *strength* are particularly important under two other conditions: First, we are often faced with the task of predicting behavior, and in such cases there is no behavior to measure, and there are no properties to report. We know from our empirical work that the various response measures we have been discussing are correlated with a number of independent variables, such as contingencies of reinforcement, the presence of relevant discriminative stimuli, and various motivating operations. Although we cannot measure future behavior directly until it occurs, if we know the status, or the future status, of these other variables, we can make an educated prediction about changes in response probability.

As a practical demonstration, consider the assignment of getting someone to give you a pen. The baseline probability that a person will suddenly give you a pen is quite low, but you can easily dramatically increase the probability simply by asking him for a pen, or by offering to pay him, and so on. One could offer very mild hints that are likely to fail, such as patting one's pockets while holding a blank notepad, or one could employ powerful incentives that are sure to work, such as threatening him with a gun. Since there are many gradations in between these extremes, the notion of a continuum of response probability or strength is intuitively plausible.

In addition to the prediction of behavior, there is a second circumstance in which the notion of response strength is helpful. When a potentiating variable is present, we suppose that the relevant response increases in strength even if it is not actually emitted. Common experience suggests the validity of this conception: When a panhandler asks for spare change, we have an increased tendency to respond, even if we uncharitably continue walking with our wallet intact. Sometimes when we see an acquaintance, we can't think of his name, but we report its strength by saying, "Its on the tip of my tongue!" That is, the correct response has a much higher strength than that of other names, even though, in a sense, the response does not yet exist. This is plausible, for even the weakest supplementary prompt may be enough to evoke the name: an initial letter, a sound pattern, his wife's name, and so on. Likewise, in conversation we may be bursting with eagerness to interrupt the speaker with some clever remark, but courteous listening is just a bit stronger, and we merely squirm and make a few incipient pips of noise. It is apparent that the two incompatible responses—speaking and listening patiently—are both strong, but they cannot both occur. As in the case of the tip-of-the-tongue phenomenon, the strength of the missing response becomes apparent when the speaker pauses ever so slightly and we jump in with our dazzling comment. Thus the interpretation of everyday behavior in complex environments requires the concept of response strength.

I have argued that the notion of response strength is useful in predicting future behavior and in discussing the status of absent behavior. I trust that the reader has found this claim plausible. But it commits us to a rather puzzling position. Everyone is content to speak of observable behavior, for it is the foundation of our science and indeed the foundation of any paradigm in psychology that aspires to the status of a science. In addition, radical behaviorists are happy to speak of covert or unobserved behavior in the same terms as observed behavior. This stance, I believe, is clearly valid, for the observability of a response is not a property of the response but of the vantage point and tools of the observer. Imagine walking past a room where you hear someone speaking. As you continue down the hall, the speaker's voice becomes fainter and fainter and eventually entirely undetectable by you, but it would be absurd to claim that his

behavior had ceased to be interpretable by behavioral laws. Alternatively, the speaker could speak more and more softly until no one could hear him, but you could detect the behavior by using an amplifier. Slight muscle movements are unobservable unless made public by an electromyograph. Thus what is observable and what is unobservable is not an inherent property of behavior but shifts according to the tools and vantage point of the observer.

So it is quite respectable, I believe, to acknowledge that some of the behavior of the organism is likely to be unobservable at any moment, but that acknowledgement does not force us to modify our box of conceptual tools. However, our discussion of response strength commits us to extending our behavioral principles not only to covert responses but to responses that have not even been emitted. That is, in addition to the rather arbitrary threshold of observability, there is another more meaningful threshold between emitted behavior and potential behavior, as Figure 1 suggests.

The concept of a threshold of emission may be misleading, for it implies that responses above a fixed value of strength will be emitted, whereas responses below that level will not. However, whether a response is emitted depends partly on the status of competing responses. A "weak" response might be emitted if no other behavior within that responses system is strong. Nevertheless, I think the concept of a threshold is helpful as a heuristic, for there is presumably an important difference between a response that is emitted and one that is not, regardless of their absolute levels of strength. Presumably emitted responses have effects that can serve as controlling variables for subsequent events.

We assume that the concept of response probability applies to all three levels of behavior: latent behavior, covert behavior, and overt behavior. It is the first of these that is our present concern, but in what sense can we say that a response that has not been emitted exists? How can something that does not exist have "strength?" I hope to show that not only can this topic be brought into some kind of order but that it is essential that we do so if we are to account for many commonplace human phenomena.

We will begin by considering the concept of the behavioral repertoire. We commonly speak of a response being in one's repertoire, as though the repertoire were a thing, a place, or a container. Moreover, we implicitly acknowledge, when we use such constructions, that the responses of which we speak are only potential behavior, not necessarily behavior emitted or observed. It is important, of course, that we avoid reifying concepts, and we should not think of the repertoire as a thing. To say that something is in someone's repertoire means only that, owing to a history of exposure to contingencies of reinforcement, a response has come under control of various independent variables. All other things being equal, the response can be evoked by a favorable arrangement of those variables: In the presence of the tone, the rat will press the bar; in the presence of the problem *6 times 8,* the student will say "*48*." Thus the repertoire is not a place or a thing but a collective term for the effects of a set of historical events.

Likewise, when we speak of a response in the repertoire we mean only that certain behavior

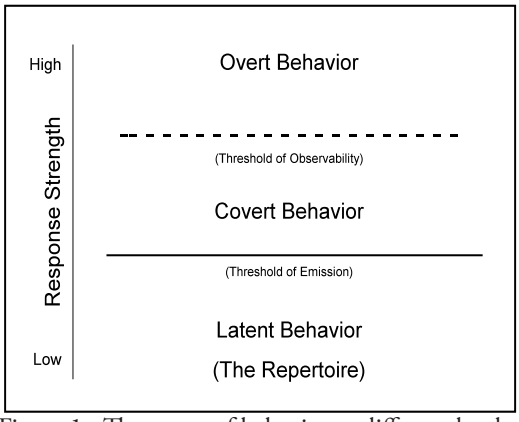

Figure 1. The status of behavior at different levels of response strength. Previously acquired behavior can be said to be "in one's repertoire" but is latent if current variables evoke competing behavior more strongly. But shifts in stimulus control can favor the target response so that it becomes the dominant response in its response system. It is emitted. Emitted behavior can vary in strength, but whether it is observed depends upon the vantage point and tools of the observer.

can be evoked by a particular constellation of variables. Contingencies of reinforcement do not create an independent entity called a response; rather they create an enduring tendency to behave under particular conditions. In the absence of those conditions, there is no behavior. The behavior is not in the organism but in the relationship between the organism and its world. Therefore, when, as observers, we speak of response strength in the case of a response that has not been emitted, we are not tacting the response itself but its controlling variables. The behavior does not yet exist, but its antecedents are very real. If latent responses can fluctuate in strength as a function of antecedent conditions, as I will show later, then there must be physical, or physiological, dimensions of these changes; however, it is unclear whether such changes can be tacted.

Response Strength is Continuous

The relationship between a response and its controlling variables is not all-or-none, but is continuous. That is, discriminative stimuli and other controlling variables can vary from near to far, clear to obscure, powerful to weak, identical to the training conditions or merely faintly similar, and their effect will be correspondingly graded from strong to weak. Second, most responses have multiple sources of control that are presumably additive. Thus a response will be only weakly potentiated by a single stimulus that only crudely resembles the original training stimulus, but it will be strongly evoked by multiple variables that are tuned to the task. For example, the response *pen* might be weakly evoked by the sight of a cigar but strongly evoked by the joint effect of a conspicuous pen, the printed word *pen,* the spoken words "mightier than the sword," hearing someone say *pen*, an attentive audience, and motivational variables that make asking for a pen strong.

The additivity of response strength seems plausible and consistent, and it is one that was explicitly embraced by Skinner, but is there any evidence for it? I will discuss two:

The Summation of Response Strength

Let's begin with a demonstration experiment that I call the "intraverbal game," variations of which are common among puzzle aficionados. Recall that an intraverbal is a verbal operant that is occasioned by a preceding verbal response, either textual or vocal, because a history of contiguous usage. For example, the verbal stimuli *To be or not…* will evoke, in most people, the response *or not to be.* Likewise, *Life is a tale, told by an idiot…*will tend to evoke *full of sound and fury.* The usage need not be literally contiguous: *bull* and *cow, bread* and *butter, tea* and *coffee* are intraverbally related, although one only rarely hears *bull-cow, bread-butter,* and *tea-coffee* with no intervening words. One hears them in the same context, but not necessarily in the same breath. Nevertheless, in the context of one member of the pair, the other occurs frequently enough for an intraverbal relationship to develop.

Intraverbal control can develop entirely within the repertoire of a single speaker, rather than from the interaction of two speakers, and indeed this may be the commonest case. The paradigmatic example of answering "Four" in response to "What is two plus two?" is clear but relatively uncommon. When we speak, we ordinarily hear ourselves speak. The auditory properties of something we have just said are ideally positioned to acquire control over what we are about to say. If we rehearse a speech, a poem, or a famous soliloquy, or if we repeatedly utter clichés or distinctive expressions, we strengthen intraverbal control. However, if attentive listening entails covert echoic behavior, as I am inclined to believe (cf. Schlinger, 2008), intraverbal control is also being established continually as we listen to others, even in the absence of discrete episodes of reinforced responding on our part. (See Palmer, 2005, and Schlinger, 2009, for further discussion of the conditioning of the behavior of the listener.) The reinforcement of intraverbal responses in one's own speech or in running echoic behavior is clearly not discrete and must be subtle, but as I have argued elsewhere, reinforcement for effective listening, although intangible, is undoubtedly present (Palmer, 2005).

As an aside, intraverbal control is presumed to be direct. The response *12* is intraverbally controlled by the stimulus *4 x 3* in most educated people, because of a history of contiguous pairings, but we would not say that the response *609* is intraverbally controlled by *21 x 29*, for the response is not primarily controlled by the verbal stimulus but rather by a set of mediating calculations. Intraverbal control requires a history of fairly close conjunction of one verbal response with another. It is a mistake to assume that any answer to a question is an example of intraverbal control.

According to the preceding discussion, the presence of an intraverbal stimulus will increase the strength of the intraverbal response. But that does not mean that the response will actually be emitted. For example, if I were to utter the word *banana*, it is quite unlikely that a listener would respond by saying the word *peel*, though they are intraverbally related. There are many responses one might make to the word *banana* other than *peel* and in any case, conversational contexts tend to evoke thematic social behavior, not the uttering of a barrage of intraverbal responses to everything a speaker says. Thus we can postulate a change in strength without postulating that the response will be emitted. To the contrary, it is only the exceptional intraverbal response that actually gets emitted. Usually a verbal stimulus occasions a saltation in response strength, but not the actual emission of an intraverbal response.

The point of the following demonstration is to illustrate the additive effect of intraverbal control, summed over stimuli that are presented sequentially. This effect is presumably just a special case of the phenomenon of multiple causation that is discussed at length by Skinner (1957). I present, below, a series of words. Cover them with a slip of paper and slowly reveal them, one by one, at the rate of one every two seconds. Each one is an intraverbal textual stimulus that weakly evokes a common target response, and your task is to figure out what that common response is. Each stimulus when presented alone is unlikely to evoke the response, but when presented sequentially, their effects will sum, and the target response is likely to be evoked, at least in a typical British or Scandinavian reader. (Whether it has a similar effect on others will depend on their intraverbal histories. Each intraverbal repertoire is unique, and no demonstration of this sort will affect everyone the same way.)

What word comes to strength as you look at the following words or letters?

GOD
OLD
MYTHOLOGICAL
NORSE
SUPREME
WEDNESDAY

As the reader may have guessed, the target word was Odin, (or in Old English, Woden), the Norse god who gave his name to Woden's Day or Wednesday. The point of this demonstration is that each stimulus word is unlikely to be sufficient to evoke the response *Odin* in the sort of strength to be actually emitted as a response, at least for most people. Rather, each stimulus potentiates a wide variety of verbal responses, and perhaps a few nonverbal responses as well. The stimulus *Wednesday*, for example, is intraverbally related to a wide variety of responses, but *Odin* is likely to be among the weakest. The cumulative effect of the stimuli, however, was to strengthen a single response to the point that it was emitted (or so I presume), either subvocally or out loud. (If this demonstration was ineffective for the reader, he or she can easily imagine another sequence of stimuli that would have worked for a different target response.) The demonstration illustrates my earlier point that an interpretation of human behavior requires us to analyze changes in probability not just of overt and covert responses but of responses that have not even been emitted.

Notice one of the implicit assumptions of this demonstration: A single verbal stimulus has a simultaneous evocative effect on a wide variety of response. The stimulus *God* is intraverbally related to many responses including *Save the Queen, damn, is great, bless you, forsaken, Jesus, Zeus, Allah, Odin,* and many others. If our account of the demonstration is correct, then the strength of all of those responses increased simultaneously when the stimulus was pre-

sented. A complete behavioral analysis must include a consideration, not just of the effect of the stimulus on emitted behavior, but on all of these potential responses as well.

A demonstration of this sort does not address the possible role of mediating behavior. The experienced learner may be engaging in covert verbal behavior while scrolling through the list of words—behavior we might call *problem solving—a*nd we cannot dismiss the possibility that the target response is evoked in part by the stimulus properties of these covert responses, for much human behavior can be interpreted in this way. (See, for example, Donahoe & Palmer, 1994, Chapter 10). Nevertheless, the claim that saltations in response strength are additive is parsimonious and apparently adequate to account for the performance without appeal to collateral behavior. Moreover, the account is supported by experimental procedures in which response latencies are so short that there is little room for mediating events, as will be discussed next.

Experimental Evidence: The Semantic Priming Procedure

A parlor game of this sort makes its point intuitively, but fortunately experimental evidence can also be adduced. The semantic priming procedure is a behavioral procedure that has been exploited hitherto mainly by cognitive psychologists. (For an extended discussion of the behavioral implications of the semantic priming procedure, see Donahoe and Palmer, 1994, Chapter 9. For relevant empirical work with this procedure within behavior analysis, see Barnes-Holmes, et al., 2005, Haimson, et al., 2009, Hayes & Bisset, 1998, and Katz & Palmer, 2005.) Many variations of the procedure have now been investigated, but in the paradigmatic example, a word is briefly flashed on the screen. Shortly thereafter, a second stimulus is presented that is typically either a non-word, an unrelated word, or an intraverbally related word. The subjects' task is to press one of two keys indicating whether or not the second stimulus is a non-word. The measure of interest is response latency, which the reader will recall is one of our measures of response strength.

A protocol might proceed like this: A warning stimulus, e.g., a tone, is presented briefly to signal the beginning of a trial. The screen is blank for a quarter of a second and then a word appears, such as *BREAD*. It disappears after a quarter of a second, and a new stimulus appears. It might be the intraverbal *BUTTER*, or a nonsense word, or the unrelated word, *HIGHWAY*. Since *BUTTER* is a word, the subject presses *1*, and the trial ends.

The typical finding of such experiments is that subjects respond on average more quickly to intraverbals than to unrelated words. This is just what we would expect from our discussion of response strength. The stimulus *BREAD* increases the strength of a wide variety of other responses with which it is intraverbally related. When the textual stimulus *BUTTER* appears, it strongly evokes the corresponding textual verbal operant *butter*, at least subvocally. But the response *butter* has already been strengthened by the stimulus *BREAD*. The summation of the two sources of control lead to a stronger response with corresponding shorter latency. In contrast, had the target word been *HIGHWAY*, the textual response would have been the only source of control. It would be sufficient to evoke the relevant textual response, but the response would have been recruited from an initially very low level of strength. It would not have had the head start provided by a topographically similar intraverbal response. There are many parametric and procedural variations that account for some of the variance in performance, but the facilitating effect of intraverbal control is robust, confirming our informal observations that response strength is additive. (See Neely, 1991, for a review of the early cognitive literature on priming. The literature is vast, but the interpretation of the data commonly differs from that presented here.)

A second finding of particular relevance to the present discussion is that a single categorical priming stimulus, such as *BIRD*, has been shown to potentiate, on separate trials, a variety of exemplars, such as *ROBIN, SPARROW, GOLDFINCH,* and *CANARY* (e.g., Becker, 1980; Lorch, 1986; Neeley, 1977). This is noteworthy, because it confirms our hypothesis

that a single word will simultaneously potentiate a wide variety of intraverbal responses. It must be so, since subjects have no way of knowing in advance which target word is going to appear. If they all show potentiation on separate trials, it must be the case that they are all potentiated simultaneously. Once again we see behavioral effects below the threshold of emission: The subject does not actually emit the intraverbal response *sparrow*, *robin, goldfinch,* etc. but the saltation in response strength is revealed when the textual stimulus appears. Such effects must be brought into consideration if we are to provide a comprehensive account of human behavior.

Exploiting the Additivity of Response Strength in Problem Solving and Recall

I think that what I have presented so far is plausible, but notice its implications: Suppose I were to say to you, *The Norse god, Odin, would have loved Dolly Parton.* It would take only a couple of seconds to utter the sentence, or for you to read it, but there would be innumerable behavioral effects. We have already had occasion to mention the myriad responses that are intraverbally related to the word *god,* but that is only one of perhaps six content words in the sentence, each of which undoubtedly has many intraverbal relations. Our discussion so far suggests that in those few seconds each listener's repertoire was boiling with activity, in the sense that a very large number of latent responses underwent a change in probability. Moreover, a speaker can normally hear himself speak, and it is plausible to assume that he too is experiencing the same medley of behavioral effects. Expanding our temporal window only compounds the complexity: since reading that sentence you have read another 140 words, many of which must have had comparable intraverbal effects.

We are forced to assume that a typical conversation includes a nearly incalculable number of behavioral effects that sum with one another, compete with one another, or are neutral with respect to one another. Thus emitted behavior will be, in part, a response to environmental variables, but also in part a synthesis or summation of positive and negative changes in strength of myriad intraverbal relations. So multifarious are such influences that Skinner's discussion of multiple causation must be brought to bear on almost every instance of verbal behavior. That is, emitted behavior is the product of many concurrent variables whose effects must be summed algebraically. Speaking metaphorically, we can say that the repertoire is a simmering cauldron of operants, rising and falling in probability, continually being stirred up by stimuli, working their way up to the top of the broth, where, elbowing one another aside, only the strongest are emitted.

If there were no practical implications of this interpretation it would be idle, but much human behavior exploits this view of the repertoire. Both problem solving and recall are processes of working on one's repertoire to increase a target response to the point that it is emitted. A few weeks ago, I challenged a graduate student with one of my standard demonstration problems, namely, finding the integer square root of a number:

"What is the square root of 841?" I asked. "It's an integer. Do it out loud."

"I don't know," she said.

"Figure it out," I said. "I've got all day."

Stripped of self-deprecating remarks and other irrelevancies, this is what she said:

"Well, it's less than 100.
50 times 50 is . . . 2500, so it must be smaller than 50.
10 times 10 is 100, so it's bigger than 10.
20 times 20 … 400. Too small.
30 times 30 is 900. Oh!
It's between 20 and 30.
20-something, but twenty-what?
21? It might be 21.
22. . . 23 . . . 24 . . . 25 . . .
It's close to 900, so it must be in the high 20s.
28 or 29?
28 times 28 would end in 4.
29 times 29 would end in 1.
It must be 29."

We can interpret this performance as the gradual potentiation of a latent response in her repertoire. The target response was, of course,

"29." That it was in her repertoire is beyond question, but the salient fact is that it was not among the various responses that were emitted in response to the question, "What's the square root of 841?" and therein lay the problem. If the response were among her emitted responses, as it might have been if she had encountered the question before, there would have been no problem, either for her, or for those of us who would try to interpret her behavior. As an experienced problem-solver, she knew how to proceed: She set about to provide herself with supplementary stimuli, and these were sufficient to eventually evoke the target response.

I will now offer a visual metaphor that I hope will make the process clearer, a "flask metaphor" of response probability. I want to remind the reader that this is meant as a heuristic only; nevertheless, I think it works as a visual aid. The Y-axis represents response strength. Most of the responses in one's repertoire are quiescent and lie at the bottom of the scale at a negligible level of response strength. In response to ambient stimuli, some latent responses have considerable strength, but they fall well short of the threshold of emission at the top of the flask. Some responses are subsiding in strength, some increasing, according to circumstances. One lucky response had enough strength to exceed the threshold and was emitted as a response. A couple of others are at the throat of the flask.

The bottleneck represents the fact that, in any one response system, most responses are mutually incompatible. We can walk to the left of a tree or to the right of the tree, but we can't do both. We can say, "Hello," or "Hi there," but not both, at least not at the same time. Response competition is an important concept. If we tried to engage in every response that had some strength, our behavior would be chaotic. If two incompatible responses are roughly equipotent, only one will actually be emitted. The competing response appears to be inhibited, as I will argue later.

We can apply our metaphor to the interpretation of the square root problem as follows: We can assume that the question initially evoked a wide variety of mathematical concepts, but none to the point of emission. Presumably many numbers, among other responses, were very weakly potentiated. One would be more likely to blurt out "74" than "Aardvark." The first prompt, "Less than 100," potentiated a subset of those numbers and concepts, while some of the others remained unchanged, or perhaps subsided in strength. Several prompts later, the intraverbal strength of "twenty" was very strong, and the response "twenty-something" was actually emitted. The process of winnowing continued until only two relevant responses were strong, but they were mutually incompatible; they could not both be emitted. A final test, "ends in 1," was sufficient to decide the case. "Twenty-nine" was emitted as the target response.

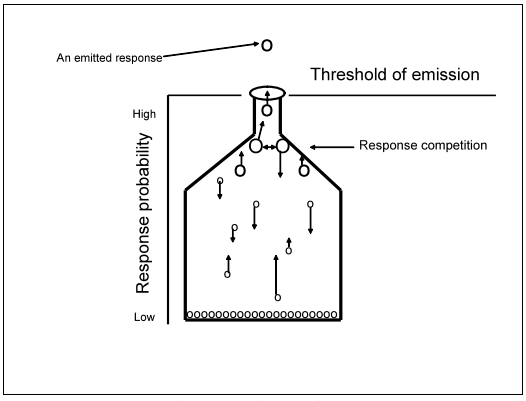

Figure 2. A visual metaphor of variations in response strength. Most responses that have been acquired are quiescent because discriminative stimuli are absent or because of the status of relevant motivating variables. At any time, some behavior is likely to be potentiated by controlling variables, and that potentiation is represented by height. Ambient variables might increase response strength still further, or weaken it, as indicated by the arrows associated with each response. Potentiation sums, and when responses are sufficiently potentiated, they are emitted. Within a response system typically only one response can be emitted, as represented by the bottleneck. There are presumably mutually inhibitory processes among responses that ensure that the strongest response gets emitted smoothly and not as a blend of two or more competing responses of roughly equal strength.

In this example we see how the subject implicitly took advantage of our conception of the fluctuating strength of latent responses in her repertoire. She "worked" on her repertoire, successively increasing the response strength of a smaller and smaller class of responses. Each prompt summed with previous prompts to make members of that class more and more likely. Problem solving came to an end when a single response in the class was strengthened to the point that it was actually emitted. One cannot be sure that such a process will necessarily lead to the correct response, but that is in the nature of problem solving. An expert problem solver is one whose strategies of self prompting have been honed by experience to yield a correct answer with a high probability. The novice may be led astray to an incorrect answer, or may simply be unable to strengthen certain members of a class of responses selectively.

One could tell a parallel story for many other types of problem-solving and for memory phenomena as well, for as I have had occasion to observe, one class of memory phenomena is a type of problem-solving. When we are asked to recall an event, the question serves as a kind of problem: "Where were you last Thursday night?" is unlikely to evoke the target response in strength, for it has not previously been emitted in response to the question. Nevertheless, we go to work on our repertoires, with a set of acquired procedures that we might call "recall strategies," successively probing and potentiating the target response, just as we would do with a math problem. Unfortunately, unlike math problems, recall tasks do not have codified solutions, so there is no typical example, but they all seem to share the feature that a target response is successively potentiated by successive probe stimuli provided by the subject. (See Donahoe & Palmer, 1994, Chapter 12; Palmer, 1991).

Problem solving and recall are two examples of complex behavior in which the summation of response strength with successive cues is relevant, but if the present account is correct, the phenomenon must be ubiquitous. Most behavior in complex settings is multiply determined.

Implications and Questions

One-Trail Learning

Human behavior is distinctive, among other ways, in that one-trial learning is commonplace. If you tell me that the men's room is down the hall on the right, I do not have to keep asking you, again and again. If you tell me that there are refreshments in the lobby, I will trouble you no further. If I open a door to discover a closet full of jewels, I will be sure to check it out again the next time I pass by. One-trial learning is common in human behavior. I believe that the reason is that in many contexts, the relevant responses already exist just below threshold strength. A small increase in strength is sufficient for the response to be emitted. Many relevant responses are strong when I am hunting for a men's room. I will turn right, turn left, climb stairs, look at labels on doors, and so on. A slight increase in probability of one such response, as from a verbal prompt, is sufficient to evoke it in strength.

A similar analysis might apply to the reacquisition of extinguished behavior in the animal laboratory. It might take a session or two to shape up a key-peck in a pigeon, but when we resume reinforcement of an extinguished response, the pigeon returns to full strength almost immediately. I believe we can interpret such phenomena this way: During extinction, the response declines in probability to the point that it falls below the threshold of emission. At that point the response no longer occurs and therefore suffers no further decline in strength. It is maintained at that strength by the experimental context, presumably as long as the ambient variables do not change. When a response is once again reinforced, it is already at threshold, and very little is required to get it going in strength.

Inhibitory Processes in Response Competition

The matter of response competition needs further analysis. As mentioned earlier, within any response system, typically only one response can be emitted at any moment. Moreover, the dominant response is usually emitted smoothly and coherently, as though there were no com-

peting behavior of nearly equal strength. Why do responses appear to be so discrete, and why do we not more commonly observe blends of competing behaviors? Blends, of course, would be maladaptive and would be punished, but what prevents first instances from happening all the time? I suggest that at the physiological level, there may be a process of mutual inhibition: Specifically, I suggest that all responses exert an inhibitory influence on all other responses in the same response system, and that this inhibitory influence is directly proportional to response strength. If it were true that all response potentiation entails such inhibition, there would be a positive feedback effect: The strongest response would exert the strongest inhibitory effect on related responses. As a consequence, not only would competing responses be somewhat suppressed, the returning inhibitory effect of those other responses would be dampened. Thus mutual inhibition would quickly lead to the dominance by a single response, and response blends would be avoided. Perhaps the bottleneck metaphor might be explained in this way. I don't know if this is speculation is right, but it is a parsimonious explanation and is consistent with the fact that the nervous system abounds in inhibitory neurons.

Does the N400 Component of EEG Recordings Measure Response Strength?

The semantic priming procedure provides an experimental method for evaluating the effect of a priming stimulus on response strength in behavior below the threshold of emission, but the effect must be inferred by comparison with a control condition and is usually apparent only by averaging data. It is thus an indirect measure of such response strength. However, some studies of semantic priming have simultaneously recorded electroencephalograph (EEG) data and have found that a distinctive waveform is correlated with semantic priming effects under the very conditions in which we should most like to have a direct measure of response strength. Specifically, it has been observed that in a priming study unrelated stimuli produce a distinctive negative waveform about 400 msec after the onset of the second stimulus. This "N400" waveform is diminished in amplitude when the stimuli are intraverbally related (Barnes-Holmes, et al., 2005; Haimson, et al., 2009). Moreover, when two unrelated stimuli are repeatedly paired in sentences that are presented to subjects, the N400 waveform evoked by the second stimulus steadily diminishes (Besson, et al., 1992; Besson & Kutas, 1993). My colleague, Daniele Ortu, has interpreted the data thus:

> I think a plausible account is that each stimulus within the sentence alters the response strength of the target response. When the target response is emitted textually the amplitude of the N400 peak will be an inverse function of the strength of the target response before the target stimulus was presented. The second time stimuli within the sentence are presented they alter the response strength of the target response so that it will be higher compared to the first presentation, as reflected by the lower amplitude of the N400 peak following the second textual emission of the target response. Eventually, after many coupled presentations of primes and target, response strength will be high enough for the target response to be emitted after the primes without the textual stimulus. An important point is that the attenuation of the N400 does not happen when the same word is used to terminate two different sentences. (D. A. Ortu, personal communication, Sept. 26, 2009)

If this suggestion is correct, it is possible that EEG data will provide another measure of fluctuations in response strength of intraverbal responses even when they are below the threshold of emission. The waveform must be measured relative to a salient stimulus, so its usefulness would be limited to a relatively narrow range of experimental preparations. Moreover, very little of the research on this dependent variable has been done by behavior analysts and none of it to directly evaluate Ortu's interpretation, so the potential of EEG data to inform our understanding of response probability remains to be evaluated. Nevertheless, if the interpretation is confirmed, the experimental preparation might provide a relatively direct measure of a phenomenon that has hitherto been evaluated only inferentially.

Donahoe and Palmer (1994) noted that data from positron-emission-tomography (PET) research can be adduced to support the assumption that fluctuations in response strength are correlated with the firing rate of populations of neurons and that such data were helpful in interpreting the results of semantic priming procedures. However, PET scans are more expensive and intrusive than EEGs, so the latter would be a welcome addition to our toolbox.

Conclusion

I have tried to show that a comprehensive interpretation of human behavior requires that we consider not just observable behavior and covert behavior, but latent behavior as well; furthermore I have suggested that the domain of latent behavior is highly dynamic. It is a boiling mixture of shifting response probabilities, and those probabilities must be considered if we are to understand the behavior that is actually emitted at any time. As we saw in the semantic priming studies, a potentiated response can be evoked more easily than a dormant one. Moreover, as we saw in the problem solving example, and the intraverbal game, potentiation sums algebraically.

Skinner devoted only a few pages of his great book to the topic of the intraverbal, and I think it is commonly seen as a kind of trivial verbal operant, but the present analysis suggests that it is an extremely important element of human behavior. Intraverbal effects are ubiquitous, and they probably contribute, perhaps often in only a small way, to the strength of most verbal behavior. Most verbal behavior is multiply controlled, and intraverbals are likely to be among the controlling variables of any instance.

It is important to note that response strength is a reflection of the status of the variables that control behavior and should not be viewed as a property of the response as an independent entity. Like all hypothetical constructs, a concept of response strength may invite reification and subsequent circular reasoning. When behavior is overt, its latency, amplitude, etc., can be observed directly without any appeal to a concept of response strength, and when behavior is covert, the status of observable discriminative stimuli, motivating operations, and other controlling variables can likewise be observed without such an appeal. Perhaps it would be more precise to do without the concept altogether. I would be more reluctant to invoke it if I were not persuaded that there are unifying physical instantiations of response strength that do indeed play a role in the control of behavior. Perhaps, as suggested above, the firing rate of a relevant population of motor neurons is the unifying physical event, and perhaps such events are sometimes discriminable. Skinner's concept of the descriptive autoclitic depends, at least in some cases, on the assumption that response strength is discriminable: "I hesitate to say ….", "I've been dying to tell you …", etc. It is true that sometimes such responses might be controlled entirely by the independent variables of which the putative behavior is a function, but in some cases it appears that they are controlled more directly by a property of behavior that remains below the threshold of emission: "I am bursting with news!" "It is on the tip of my tongue," etc.

I close, then, with the suggestion that the conception promulgated in this paper is helpful in understanding the complex interplay of events that is characteristic of most behavior. I acknowledge that I am uncertain whether the concepts of response strength and response probability are necessary, but I think they do more good than harm. It is perhaps salutary to recall that Skinner himself, who alluded to response strength and response probability continually, wrestled with doubts about their status:

> I am currently not happy about the notion of "probability of a response." It would be nice to adopt a pure frequency theory of probability, but this obviously won't work in talking about multiple contributions to the probability of a single instance. I don't know of a better term, however, and I believe that we are dealing essentially with a probability function and that it will do no harm to reiterate this by adopting the term. This is one point where a further systematization will be most valuable. For that matter, I am not happy with the present status of the response as a unit of behavior, and in our animal work

we are, I think, moving slowly toward a more flexible formulation—one which will reflect the continuous flow of behavior. The notion of a verbal "atom" is a simple step in that direction. (Skinner, 1958)

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