A linguist's view of the Bellman-Goldberg thesis

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SMITH, MARY REGINA. *A linguist's view of the Bellman-Goldberg thesis.* Am. J. Physiol. 246 (Regulatory Integrative Comp. Physiol. 15): R922–R924, 1984.—From a linguistic perspective, the Bellman-Goldberg thesis of a necessary relationship between the abilities of organisms to move and communicate is very interesting. Since several concepts and terms are represented in both the thesis and contemporary linguistic literature, these items are discussed in further detail. Questions of the implicit assumptions of the homology of the motor and linguistic systems are also raised here. Finally, there are requests for further clarification on issues of evolution in this test of the strength of the thesis.

chemical symbols; code; cipher; physical constraints; context-sensitive rules

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I FOUND Bellman and Goldberg's (1) synthesis of ideas about symbols and movement very interesting but difficult to follow. I offer three types of remarks here: *1*) relief from having to wrestle with certain claims in the literature about human language and linguistics, *2*) encouragement to explore further certain comparisons between the properties of grammars for natural human languages and those of other symbol systems, and *3*) a challenge to defend further their ideas on the evolution of symbolization and movement.

For relief, I offer three points I hope will reduce the authors' concern for the study of unique characteristics of human languages. *1*) Few linguists seriously doubt the biological foundations of human linguistic abilities; some, like Lenneberg (4) and Chomsky (2) have posed the same questions as the biologists

> In a certain sense all organisms are self-regulating systems, and, therefore, the question which faces us is, "What is the degree of freedom with which the specific organization necessary for language processing comes into being . . . we must assume a biological matrix with specifiable characteristics that determines the outcome of any treatment to which the organism is subjected" (4).

By identifying the relationship between internal chemical communication and movement, Bellman and Goldberg have begun to help identify the properties of the biological matrix.

2) Bellman and Goldberg do not need to make the case that humans cannot produce infinitely many sentences or manipulate infinitely many symbols. These are misreadings of the implications of a fact about every natural human language—that English, for example, has an infinite number of grammatical sentences. Note that grammatical does not mean meaningful in the ordinary sense. There are many ways in which we can generate these sentences, just as there are algorithms for generating the positive integers. The implication of this fact is that the grammar of the language must be capable of generating an infinite number of grammatical sentences. This grammar is our model of what the speaker-hearer knows about the language; it is not a complete model of what the user does. We wish to understand the competence of the language user, not just the performance capabilities. To do this, we consider an idealized speaker-hearer. The real point about the infinite number of grammatical sentences is that every normal language user is capable of understanding any one of an infinite number of novel grammatical utterances even without having heard very many sentences at all (on a lifetime scale). The rich capacity of the user seems to far outweigh the particular experiences with the language. Bellman and Goldberg need not fear that the formal explicit models of what the human knows about the language will require him to perform impossible feats.

Bellman and Goldberg should be relieved to see that some of their disagreements with those looking at the evolution of human linguistic abilities come from different definitions of terms. For example, the term "linguistic process" has a special meaning within a theory of linguistic competence. To show that this meaning should be extended to other sorts of systems would be to show that both the particular properties essential to linguistic processes (which we have yet to discover in satisfactory detail) and the principles governing the processes are also the essential properties and principles of the other systems. That all organisms obey certain laws of thermodynamics is not a sufficient condition to unite or equate all processes at all levels. The principles may be constrained by the laws, but that does not make them equivalent to each other.

Another term that has special status is rule. Here two important points can be made. First, there is a distinction between behavior that obeys a rule and behavior that involves a rule (Wittgenstein). Consider a normal adult speaker of English who knows how to form the plural of regular nouns. We say that this knowledge is in the form of a rule to add the sound of /s/, /z/, or /ez/ to words like stick, bug, and match. Producing the correct plurals can be said both to obey and involve the rule. Now consider a child who produces forms intended to be plural in such a way that they rhyme with the singular. We can easily imagine a rule that removed the appropriate end-

ings from normal adult plural forms. This, however, is not how we would characterize the child's productions. These productions obey this rule, but we have reason to doubt that they involve this particular rule, because we believe that only certain sorts of formulations can be proper rules of human language in the biologically relevant sense. For another example, if we observe an individual who limps, we may be able to describe the behavior with a rule, but we may be unwilling to say that limping involves a particular rule. We may be more inclined to describe the limping as a (systematic) deviation of the normal rule. We must be careful to appreciate the constraints on what counts as a rule and how the rules enter into the total explanation of the activity.

A second point about the term rule is also relevant: not all systems of symbols and rules are alike. In the study of human language grammars we have found it necessary, for a coherent total picture, to represent the user's knowledge in sections, each of which has symbols and rules. The properties of the rules are different in each section. For example, the rules in the phonological component (concerning the interrelationships of meaningful sound units, like the plural endings) appear to be ordered with respect to each other (so we get governments and not governsment), are context sensitive (for the plurals, /s/ goes with /t/ and /z/ goes with /g/), and are structure dependent (the plural comes at the end of the noun). In contrast, in the syntactic component the rules are unordered, context free, and structure independent (H. Lasnik, personal communication). Our model of grammar has distinct rule types with special cooccurrence conditions. The lesson is that before we ask why or how, we must have a commitment as to what linguistic knowledge is. The current linguistic hypotheses may not be satisfactory material for the comparisons Bellman and Goldberg wish to make.

Let me now offer encouragement in the form of questions about similarities between some of the points made by Bellman and Goldberg and modern linguistics. First, language and movement abilities have been associated necessarily in all organisms, whereby the authors intend language to mean at least the rule-governed finite chemical symbol system. I take this to entail that no organism has the capacity to move without the capacity to use chemical symbols, because moving necessarily involves organizing a response, a time-consuming activity, and the time delay is made possible precisely by the presence of chemicals whose concentrations change faster with respect to the external than to the internal environment. In more general terms, does this mean that the physical properties of the symbols (e.g., their lability) are biologically compatible with the properties of the organized response? If the response requires some *time x* to become coordinated, then only those symbols with particular properties (e.g., binding sites) can participate in the symbol pool, since only these will enchain the required delay.

At the physical level we have the particular transience of the visual and auditory signals in sign and speech. These signals then must change and persist in just such ways that the physical responses of the sensory systems can capture the effect of the fluctuating energy in biotransducers. I gather that requiring chemical symbol-to-movement compatibility leads to the conclusion that there is a match between the response of human vocal tracts and the response of ears. That is, the speech production system acts on a time scale appropriate to the energy transmission properties of the gaseous media and on the time scale of the resolving power of the auditory system. By hypothesis, we could not evolve to use another medium without also evolving the ability to use those chemicals that would be required to adjust to the faster or slower changes in the new medium. (For example, what would we need to be sensitive to radio waves?)

Second, consider the relationship of the symbol to the organism and the environment, which Bellman and Goldberg note is not just a case of chemical analogues. They further note that the chemical symbol is a description of both the organism and the environment. Given the physical constraints involved, the class of possible chemical symbols for a given relation of organism to environment must be finite. The relationship of organism to chemical to relation is fixed to some degree. That is, not all chemicals will be information about the relation to all organisms. (Hunger is not specified by the same chemical symbol for anerobic bacteria and me.[1]) Therefore it is not surprising that the human symbol set is not shared by other species. (This does not mean that the relations are not shared.)

For human linguistic symbols, there appear to be some physical constraints on possible sounds and signs but not the same constraints on what the unit (word) may refer to. The meaning of a word may change (for an individual and for different people) in a way that we do not see the adenosine 3′,5′-cyclic monophosphate (cAMP) changing in relation to the organism and glucose. Are there any examples in which the physical constraints do not bound the novelty or creativity in chemically symbolizing relations?

Third, with respect to the issues raised about rules above, is there evidence of the cooccurrence of properties of the rules governing the chemical symbol systems? Is it meaningful to speak of context-free rules in this system? We speak of context-sensitive rules in those cases where no other principle or rule dictates the outcome. If the chemical symbol set and relevant laws are well enough understood, then it seems that no chemical rules would ever need to be context sensitive, because some other description of a more general character (e.g., molecular orbital theory) would predict the activity of the chemicals.

Perhaps a more interesting issue concerns the different kinds of rule-governed systems. Bellman and Goldberg have accepted that the finite chemical symbol set and its rule set should constitute a linguistic system. There are, however, two types of rule systems: codes and ciphers (e.g., 4). By code, we mean the restructuring of information. By cipher, we mean a lower-order translation of

[1] *Editor's note*: As a matter of fact, Tomkins' argument is that the mammalian and bacterial response to cAMP and other symbols is quite similar (see Ref. 1).

information. From Bellman and Goldberg's discussion of Tomkins' work, cAMP is at least an encipherment of the state of glucose availability. Bellman and Goldberg have not shown that the relation of symbol to glucose is that of a code. Only codes are relevant to natural human languages. Consider two sentences and the task of judging whether one is good paraphrase of the other. No methods are available (nor are they likely to be) that can provide the answer based on the physical properties of the signals. The relevant physical properties of the signal encode the linguistic messages. One must know the grammar of the language to provide the paraphrase judgment; the grammar is the complex code between the message and the signal.

Many more such issues can be raised about the relationship of natural language grammars and other grammars. I want now to offer some challenges based on the evolutionary status of language and movement. Bellman and Goldberg object to the claim that "communication is somehow a higher-order function than movement skills" and imply that we cannot imagine "a behaving organism that secondarily evolves into a communicating one." I did not find their evidence compelling *1*) that the order of functions of communication and movement must always evolve at the same pace, *2*) that the order of one is linked to the other, *3*) that evolution could not be abrupt, and *4*) that selection pressures (or whatever) should select for the cooccurrence of functions of the same order and these functions in particular.

The authors argued well that to move will require chemical symbols. I understand the obverse is that to acquire the chemical symbols requires energy-intensive processes (e.g., active transport, synthesis, and metabolism) and to maintain the energy requires movement toward food. One could imagine a creature (rather like a plant, I guess) where the relationship of energy to movement is different, yet the symbol system is advanced. With respect to evolution, we need not think that selection has been directed at either or both functions specifically. For example, we have the capacity to do astronomy, but do we think of selection pressures for this, or do we accept that this capacity is compatible or emergent given other traits for which selection operates? Perhaps our natural language capacity emerged only after some other order of communication function was reached and in the absence of further changes in the order of movement functions.

If the authors accept the picture presented by Iberall (Ref. 3 and works cited therein), then there can be sudden and fragile solutions to maintaining stability in the fluctuating energy fields in the form of organisms not entirely evolutionarily connected with the previous "neighbors" on the manifold. There will be significant differences in the types of grammars that species may have, even if each species has the compatibility of symbolization and movement functions suggested here.

Lastly, if this is the story of communication, what is the story of memory and knowledge?

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