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SPAN ABILITY AND THE RESPONSE STRING: TWO CONSTRUCTS RELEVANT TO STRUCTURAL ANALYSIS OF COMPLEX BEHAVIOR

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Abstract

Span ability and the response string are two constructs that may be useful in a behavioral analysis of the structure of complex behavior including language. Span ability is conceived not as memory, but as a limit on *S*'s ability to respond to complexes of discriminative stimuli. The response string, which superficially may appear identical to a response chain, differs from the chain in that the controlling stimuli of the response string reside in the stimulus complex rather than in the response sequence.

Older or more intelligent *S*s are able to produce response strings of greater complexity than younger or less intelligent *S*s. This ability to respond differentially to complex stimulus prompts can be related to the development of complex repertoires and thus predict more rapid acquisition of complex behaviors among *S*s with larger spans. The relation between the concepts of response string complexity, behavioral complexity, and intelligence were explored.

Span Ability and the Response String: Two Constructs[1] Relevant to Structural Analysis of Complex Behavior

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In the memory span experiment *E* presents a series of auditory or visual stimuli (words, digits, letters, colors, geometrical forms, etc.) and *S* attempts to report or label all the stimuli. The average college student does very well on one to six stimuli but begins to omit expected responses when more stimuli are presented. Measures of the absolute number of stimuli which *S* can report or label are called span measures. The empirical characteristics of span ability parallel the characteristics of the hypothetical constructs of mental ability and intelligence: (a) Retarded individuals have smaller spans than normal individuals of the same age (Butterfield, 1968; Galton, 1887; Jacobs, 1887; Korst & Irwin, 1968 a, b). (b) Students at the bottom of their class (by teacher evaluation) have smaller spans than students at the top of their class (Jacobs, 1887). (c) College students have larger spans than average adults (Bingham, 1916; Humpstone, 1917). (d) When corrected for attenuation, the correlations of digit span and full scale IQ (minus digit span) are +.60 to +.70 for the WISC and +.75 for the WAIS (Jensen, 1970; based on data by Wechsler, 1958). (e) The digit span has a loading of .63 (.80 when corrected for attenuation) on the *g* factor for the age group 18-19 (Jensen, 1970; based on a factor analysis by Wechsler, 1958). (f) Spans for both normal and retarded *S*s increase linearly with age until 14-20 years of age (Gundlach, Rothschild, & Young, 1927; Jacobs, 1887; Korst & Irwin, 1968 a, b; Lumley & Calhoon, 1934; Wechsler, 1958); and after age 25 digit spans begin a decline which is not associated with changes in IQ (Wechsler, 1958). (g) Digit spans and IQ scores correlate significantly in middle- and upper-class children but not lower-class children (Jensen, 1970). This result would be expected if both digit span and IQ measures are closely related to "mental ability." It must be remembered that IQ scores measure primarily achievement in school, which may be only indirectly related to "mental ability." In other words, this result would be expected if IQ is a culturally biased measure of "mental ability" while digit span is not. (h) The span is an abstract measure of behavior and individual differences; the spans for a variety of stimulus-response pools are quite comparable for an individual (Brener, 1940). (i) Practice effects are either non-existant or small, stimulus-response specific, and temporary (Bachelder, 1970; Gates & Taylor, 1925; Hebb, 1961; Martin & Fernberger, 1929, Melton, 1963). [5]

Previous researchers using memory span and other short-term memory (STM) paradigms have attempted to explain the STM phenomena in terms of hypothetical constructs

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[5]See Bachelder (2007) for an expanded discussion of the construct validity of a span test as a measure of intelligence.

such as decay of stimulus traces (Ellis, 1963) or principles of information processing (Kintsch, 1970). Following Skinner (1950) and Denny (1966; Denny & Ratner, 1970), this paper will focus on a detailed analysis of stimulus events and measurable responses and will avoid the use of hypothetical constructs or intervening variables. From a behavioral-learning orientation the series of responses produced by *S*s in span paradigms have been conceived as chains of associated responses by both Jensen (1970) and Staats (1968); and Hilgard (1951) has defined the span as the number of items which can be learned in one trial.

Interpretations of the span phenomena in terms of learning or associations are difficult to justify on either operational or empirical grounds. If *E* presents one stimulus and *S* successfully repeats, reports, labels, or imitates it, the phenomenon is usually labeled elicitation or stimulus control. If, however, *E* presents more than one stimulus, and *S* produces more than one response in sequence, the concepts of learning, association, and chaining have been invoked to explain the phenomenon, even though the requisite conditions for learning are not met in the usual span paradigm. The *S*s' behavior is observed only on the first trial in the memory span experiment, while learning, defined as a change in behavior as a function of practice and reinforcement, cannot be observed until the second trial.

It seems more parsimonious to describe both the single and multiple stimulus and response situations simply as instances of stimulus control which differ only in complexity. Short strings of discriminative stimuli exert virtually perfect control over the response strings. As stimulus string complexity increases, however, there is an abrupt point for each S beyond which stimulus control is faulty. This breakdown in stimulus control is evidenced by (a) *omissions*, in which some stimuli are not accounted for in the response strings; (b) *transpositions,* in which two or more sequential responses occur out of order; (c) *intrusions*, in which responses occur without obvious discriminative stimuli in the stimulus string; and (d) *blocking,* in which *S* fails to attempt any response at all. Stimulus control beyond span is still powerful, however, as evidenced by the fact that most of the *S*s' responding is clearly related to the stimulus string.

A response *string* is controlled by the stimulus complex and must not be confused with a response *chain*, where the controlling stimuli are the successive responses that comprise the chain itself. In practice, a response string and a response chain may be superficially identical. However, a careful functional analysis of the controlling stimuli should discriminate the two phenomena. Four arguments support the distinction between response strings and response chains: (a) Since, by definition, response strings require a controlling complex of discriminative stimuli the response string is very "fragile." Any change in the stimulus situation which produced a given string the first time will make it unlikely that the exact same string will be observed again. In information processing terms, this phenomenon is called forgetting. *E* prompts *S* (by presenting a number of stimuli) to produce a response string, then several seconds later (after intervening behavior such as counting) *S* is asked to report the stimuli and does so imperfectly. Counting has been interpreted as a procedure which prevents rehearsal of the sequence so as to provide a pure measure of short term memory. The present interpretation is that counting serves as a source of competing stimulation so that at the moment of response the effective stimulus situation has changed and cannot support the same response string as would have been possible upon immediate repetition. In other words, performance is poor after a filled delay interval not because the stimuli have been "forgotten" but because the stimuli available to control the responding have changed materially. (b) Response strings are developed immediately with no training in the usual sense; *E* simply presents a series of discriminative stimuli. Response chaining requires either formal or informal training. (c) The occurrence of response sequences without associations between successive response members has been demonstrated through the inability to pinpoint the functional stimuli in verbal serial learning (Jensen & Rohwer, 1965; Underwood, 1963, 1966). From the present point of view stimulus control might well reside in the stimuli and responses which occur prior to the immediate test trial. (d) Lashley (1951) has argued that a variety of serial behaviors cannot be described in terms of response chains for two reasons. Many response sequences occur so rapidly that there is not time for one response to serve as a stimulus in the usual sense for the subsequent response. In other cases of complex serial behavior the relations that specific responses have to other responses is so variable and complex that a given response cannot be acting as an eliciting stimulus in the usual sense. Lashley presents this example: "The mill-wright on my right thinks it right that some conventional rite should symbolize the right of every man to write as he pleases [p. 116]." In this example the word arrangement cannot be due to specific associations of the word "right."

The response string, as it occurs in span paradigms, has compelling characteristics which may help solve three problems previously inherent in behavioral analyses of complex human behavior: (a) the production of novel verbal sequences; (b) the complex relation between "intelligence" (measured by the IQ) and learning; and (c) the lack of a good behavioral ability concept which might be used to analyze "intelligent" behavior.

Novel verbal sequences. Critics of S-R and operant analyses of language development point out that language is generative, that is, *S*s produce sentences which they have not heard or practiced before (Brown & Fraser, 1963). Since the component responses of such generative sentences must have been part of *S*'s learned repertoire, any creativity or novelty in the sentence must be a novelty of sequence. This type of novelty is inherent in the response string whose content and sequence is determined by the stimulus complex. It is possible and quite common to elicit novel verbal response sequences by presenting novel stimulus complexes. In this light, the response string might serve as a core concept in a behavioral analysis of language.

Intelligence and learning. It is paradoxical that in the face of the "obvious" relation betweeen intelligence (IQ) and gross learning ability, laboratory studies of this relation have failed to find any simple relation between the two constructs (Denny, 1964; Lipman, 1963). Hovland (1951) points out that correlations between IQ and gain scores are so low as to suggest that there is no relation at all between "intelligence" and learning ability. In contrast, STM paradigms reveal clear differences in performance as a function of MA or IQ (Ellis, 1963, 1970; Scott & Scott, 1968).

One experiment (Bachelder, 1972) may point to a resolution of this paradox. High-span *S*s and low-span *S*s performed in a multitrial free-learning paradigm on words with high- or low-frequency of occurrence. The dependent measure was the number of correct words on each of 16 trials. Performance was better on high frequency lists ($p < .05$) and there was no interaction between Word Frequency and Span Level; $F = .001$ ($df = 1, 16$). Both Span and Practice were significant effects ($p < .05$ and $p < .0005$, respectively); and Span and Practice did not interact; $F = 1.12$ ($df = 15, 240$). The high- and low-span groups gained similar amounts as a function of practice; but, had the dependent variable been trials to criterion, the high-span group (having started at and maintained a higher level of accuracy) would have reached criterion sooner. This study shows how differences in the ability to respond to complex stimulus sequences might be related to rate of acquisition of a complex response yet be independent of "learning."

A behavioral concept of ability. The span ability appears to be the ability to produce complex response strings or, conversely, the ability to respond to complex stimulus prompts. The power of this conception may be suggested if one considers the implications of substituting the response string for the *R* in the S→ R→ S^R learning paradigm. In this paradigm the *S* emits an *R*, reinforcement occurs, and the response is more likely to recur. It is not unreasonable to expect that the *S* who emits a complex response string will reach an arbitrary criterion sooner than the *S* who emits a simple response string.

As an example, the typical adult attempting to "learn" a telephone number needs to hear it only once or twice to begin repeating the entire number. He could attain an arbitrary learning criterion of 10 successive correct responses in perhaps 10 or 12 trials. Contrast this situation with that of the atypical individual, or typical younger individual, with a digit span of 4 who will require more trials to reach the same criterion. In fact, without special structuring of both prompts and reinforcement he may never emit the target sequence (Bachelder, 1973). The implications for acquisition of complex repertoires is obvious.

This conception of ability differences offers a fresh approach to the analysis of intelligent behavior; it is a non-learning or non-associative conception couched in terms of the basic concept of stimulus control. It is also consistent with data which fail to reveal a simple relation between measures of learning and measures of intelligence, and with data which reveal consistent relations between measures of intelligence and measures of span and span-like behavior (Denny, 1964; Ellis, 1970; Hovland, 1951).

One must be careful not to use the concept of span ability in the same way that the constructs of mental age and intelligence have been used. We cannot explain retardation as the result of small spans. The concept of span ability must be used simply to describe observed behavior in situations that require complex stimulus control. In this sense we may speak of "span ability" in the same way we speak of *S*'s ability to respond to discriminative stimuli. As suggested by Skinner (1950) and Denny (1966; Denny & Ratner, 1970), behavioral research should focus on the description and demonstration of functional relations between stimulus and response events.

Behavioral complexity. The present span concept may be related to the concept of behavioral complexity which has been theoretically related to intelligence and language. These concepts can be summarized simply as postulating that behaviors can be arranged into a hierarchy of complexity and that difficulty of learning is proportional to the level of complexity (Denny & Ratner, 1970; Denny, 1964; Ratner & Denny, 1964; White, 1965; Gagné, 1965).

Denny & Ratner (1970) stated that behavioral tasks differ in complexity and learning rate is inversely related to task complexity. The concept of complexity was not defined but was related to tasks involving complex cues, several of which were listed:

"(1) an extended sequence of stimuli . . . ; (2) the perseverative trace of a stimulus (stimulus after-effect) . . . ; (3) response-produced stimuli, particularly when produced by minimal responding . . . ; (4) situations in which the relevant stimuli vary with or are determined by the stimulus context; for example, when the background is light, the form of the object is relevant and when the background is dark, the color of that object is relevant . . . ; (5) situations in which the relevant stimuli must be abstracted from a larger, often changing context, as in concept formation . . . [p. 718]."

The relation between these cues and phylogeny and ontogeny was summarized by Ratner & Denny (1964):

"Higher vertebrates are better able to use complex cues, as previously defined, than lower vertebrates. And, everything else being equal, more mature organisms perform complex learning tasks better than immature organisms of the same species. These trends are borne out in delayed-response learning, double alternation in a temporal maze, learning set, concept formation, and oddity learning [p. 638].

"The mentally retarded rather consistently show a deficit in the area of complex learning. . . This appears to be associated with a lessened ability to use less obvious or less available cues, as characteristic of learning set, delayed response, double alternation, oddity problem, and even problem-solving with implements [Denny, 1964, p. 120]." (Also see Denny & Ratner, 1970.)

The first of Denny & Ratner's complex cues, an extended sequence of stimuli, virtually defines the span paradigm. The four remaining complex cues have certain similarities to the span paradigm:

Complex Cue	Similarity to the Span Paradigm
(1) An extended sequence of stimuli	The span paradigm uses extended sequences of stimuli.
(2) Stimulus after-effects (delayed responding)	*S*'s responses in the span paradigm are delayed during the presentation of subsequent stimuli.
(3) Response-produced stimuli	Response-produced stimuli appear against a background of external cues and increase the complexity of the total stimulus situation. *S*s with large spans respond to more aspects of a stimulus complex.
(4) Relevant stimuli which vary with the stimulus context	*S*s must respond to two or more aspects of the stimulus situation to specify the correct response. *Ss* with large spans respond to more aspects of a stimulus complex.
(5) Abstraction of the relevant stimulus	*S*s with large spans respond to more stimuli in stimulus complexes so they are more likely than *S*s with small spans to respond to the relevant stimulus.

These similarities between the span paradigm and the complex cues suggest a definition of task complexity in terms of the size of stimulus and response strings; that is, the complexity of a task is the number of discrete stimuli which control complex response strings on each trial. The memory span paradigm illustrates variations in complexity; namely, S-R is the simplest task, S_1S_2-R_1R_2 is more complex, and so on. This conception of task complexity combined with the fact that retardates have small spans predicts the Intelligence X Complexity interaction: Very few *S*s, indeed, fail on simple S-R digit strings. In contrast, brighter *S*s produce complex strings with ease, strings which are failed uniformly by *S*s with smaller digit spans.

Not all tasks are so transparent as word strings; but they are, perhaps, measurable in terms of word string equivalents. Assuming that the principles of mixing materials are well understood, tasks of unknown complexity should be measurable in relation to a task of known complexity by requiring that *S*s do both tasks simultaneously. Thus, if *S*'s span for words is seven, but he can, on the average, produce strings of three words correctly when he is required to add a sequence of numbers, then it could be concluded that the addition problems are equal in complexity to four-unit word strings.

Murdoch (1965) did a study of this type in a test of the "limited capacity" hypothesis of immediate memory. He had *S*s sort cards and recall words and found that *S*s divide a limited amount of capacity between the two tasks.

Research. How do individual differences in span ability relate to the effectiveness of teaching? Bachelder's (1972) free recall experiment (discussed above) is suggestive here. High-span *S*s would have reached criterion faster than low-span *S*s, but they did not "learn" faster. Their faster approach to criterion is understandable in terms of their greater ability to respond to complex stimulus prompts (the reading of the stimulus lists), rather than in terms of their rate of improvement with practice.

If *S*s do differ in important ways in their responses to complex verbal prompts, then size of span may be related to the efficiency of prompting during training. For example, research is being planned to examine *S*s' ability to imitate and develop complex sentences as a function of both the complexity of verbal prompts used during training and *S*'s common word span. It is expected that each *S* will be able to develop complex sentences most rapidly when the prompt is at or just below his span. Prompts which are beyond span are likely to be less effective because *S*s will fail to emit the exact target sequence. Prompts which are below span will produce accurate components of the target sequence, but should result in less efficient acquisition because *S*s will practice less than the optimal portion of the target sequence on each trial.

To what extent does the span concept complete our conceptualization of individual differences in behavior? Observed variance of dependent variables is generally ascribed to three categories: variance which is related to variance in environmental conditions, variance which is related to individual differences in response repertoires under comparable environmental conditions, and variance resulting from sampling error. Bachelder (1970) manipulated rate of stimulus presentation, stimulus grouping, and size of span in a sequential auditory digit span experiment using retarded and borderline adults. Rate, grouping, and size of span produced significant effects but there were no interactions of span level with environmental conditions (rate and grouping).

This means that the variance could be completely accounted for in terms of four basic concepts: (a) an abstract and general span ability; (b) environmental conditions; (c) individual response repertoires; and (d) true error of measurement (not sampling error). In the same experiment IQ interacted with both rate and grouping, but this interaction was interpreted in terms of response repertoires--which is consistent with the fact that IQ measures academic achievement of specific responses to more or less specific stimulus situations.

What factors affect size of span? If span measures do relate powerfully to the acquisition of complex skills, it is natural to inquire into the possibility of improving *S*'s span. Early researchers of span behavior (reviewed by Blankenship, 1938) tended to conceive the span as an organismic condition which could not be modified by training. Aside from the fact that satisfactorily demonstrating no effect is a difficult task, the data indicate that span measures are remarkably stable under extremes of practice. Gains which have been found (Gates & Taylor, 1925; Hebb, 1961; Martin & Fernberger, 1929; and Melton, 1963) cannot be attributed to gains in a general span ability (improvement in spans for unpracticed responses), and are probably best interpreted in terms of the development of response chains. Nevertheless, no modern study has diligently applied the powerful techniques of reinforcement or learning-to-learn procedures to test the hypothesis of a constant span.

How general is the span limit phenomenon? Brener (1940) demonstrated that visual, auditory, sequential, or simultaneous presentations of digits, abstract words, colors, and geometric forms all produce similar average measures of span in college students (from 5.31 to 7.98). Bachelder (1970) found that digit spans and word spans correlated .79 in retarded and borderline adults. Gundlach, Rothschild, & Young (1927) had *S*s point to various sequences of lights arranged in a circle. They found span limits for the number of lights which could be correctly touched in order and that the size of this span was related to age just as are digit and word spans.

The span limit seems to apply to paradigms in which *S*s follow verbal instructions. Brener (1940) presented sequences of cards with printed instructions to college students and required written responses on another card. For example, when given the instruction, "Put a comma under the A" on one card, *S* responded on a second card with two letters printed on it. Span was measured as the number of cards correctly responded to. Brener's measure of "card span" is somewhat difficult to relate to spans for other stimulus materials because it is not clear how the complexity of each card might be measured. Brener, however, stated that each card had three aspects or operations. In the above example these are: (a) Put a comma, (b) under, (c) the A. Ignoring the fact that this structure is poorly defined, we may multiply the card span (2.42) by three (the number of aspects on the card) and the result is 7.26. This figure is very close to the spans for digits and consonants measured on the same group of *S*s, which were 7.98 and 7.30, respectively.

Does the span limit relate to language development in normal children? Brown & Fraser (1963) in referring to children's telegraphic sentences, state that "A basic factor causing the child's reduction of adult sentences is surely an upper limit of some kind of immediate memory span for the situation in which the child is imitating and a similar limit of progamming span for the situation in which the child is constructing sentences [p. 193]." It should also be noted that some of the errors in typical children's speech are similar to errors made in span paradigms including the omission of words (Mommy get soup.) and transpositions (See dog big.).

Is it possible and useful to measure the complexity of tasks? If the principle that intelligence interacts with task complexity is valid, then knowing the complexity of a task will allow prediction of performance. Success in this research endeavor should help advance behavioral classification from reference to the appearance of behavior to one based on behavioral structure; that is, from terms such as gross-motor and language to numbers proportional to the complexity of stimulus control required to produce the behavior.

In summary, the concepts of span ability and the response string may minimize the need for hypothetical constructs such as short term memory and mental ability. By couching traditional experimental paradigms in the behavioral terms of stimulus control, span ability, and the response string, cognitive phenomena may become amenable to a rigorous behavioral analysis. In this context it should be pointed out that most research into language and cognition is concerned with the structure of behavior rather than its function (consequences). The present span concepts refer to the structure of behavior rather than its function. As pointed out by Catania (1972), analysis of structure is entirely consistent with a behavioral approach which takes as its goals the description and analysis of behavior; behavioral analyses need not be restricted to analyses of function.

Experimental psychology is in need of a theoretically tractable conception of intelligence with at least five characteristics: (a) It must be couched in basic behavioral terms. (b) It must be explicitly related to response acquisition at the empirical level. (c) It must increase during the developmental period. (d) It must vary continuously from high to low values among *S*s and (e) It must be somewhat independent of IQ so as to reflect the role of specific experience in the development of adaptive behavior. The present concepts of span ability and the response string seem to have these requisite characteristics.

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