SPAN THEORY AND TASK COMPLEXITY ANALYSIS:
An Introduction [1]

Bruce L. Bachelder
Bachelder & Bachelder
Morganton, NC

According to Gesell, et al. (1940), the immediate memory span test ". . . taps an ability which is important for successful learning and is therefore of considerable clinical importance (p. 177)." Span tests appear on numerous tests of cognitive ability including the Wechsler intelligence tests, the Stanford-Binet intelligence tests, the *Illinois Test of Psycholinguistic Abilities* (Kirk, McCarthy, & Kirk, 1968), a test for aphasia (Eisenson, 1954), and a test of brain damage (Hunt, 1943). In the span test the subject is presented with a series of stimuli (such as words, digits, colors, pictures, etc.) and must respond with a series of discriminative responses. For example, the subject might hear the spoken words *dog-cow-cat*, and would be expected to respond with the spoken words, "dog-cow-cat." The number of stimuli to which a person can respond perfectly varies directly with mental age. Older children do much better than younger children and more intelligent children and adults outperform slower or retarded children and adults. Span theory is a theory which attempts to understand the span phenomena and the relation of individual differences in span ability to individual differences in intelligence, mental age, cognitive abilities, and language. Task complexity analysis is a group of behavioral analytical techniques used to estimate the amount of span ability required by different tasks and behaviors. Task complexity analysis grew out of task analysis and is closely related to it with the major difference being the addition of an ability construct, namely, *span ability*.

BASIC WORKING ASSUMPTIONS, CONCEPTS, AND PRINCIPLES

Span Ability

Each individual has a span ability measurable via a standard span test. Span grows during the developmental period and reaches a peak in early adulthood and appears to remain essentially constant until old age. Within each age group from childhood through adulthood there are marked individual differences in the size of spans. Individual

[1] This is a reprint (in April, 1994 and November, 2008) of two unpublished papers prepared in 1981 ("span theory" and "Glossary"). Minor typographical corrections have been made. This paper is being revised extensively. One of the changes will be to replace the terms *task complexity* and *task complexity analysis* with *span load* and *span load analysis*, respectively. It is hoped this will minimize confusion with the several other ways *complexity* is used in the literature. Comments will be welcome. [Bachelder_1981_Intro.pdf, created from WF0045.NB; PXCSMALL.SPG]

Direct correspondence to the author:
306 West Union Street Telephone: 828-430-0421.
Morganton, NC 28655-3729. e-mail: Bruce@ BruceBachelderPhD.com

differences in span underlie and account for individual differences in acquisition of various skills and language. NOTE: individual differences in span are not the only source of individual differences in intelligence. Any factor which affects rate of learning is presumed to modulate the effects of span. Thus, enriched schooling and intense training will tend to offset a relatively low span. Similarly, even a very high span must be "developed" through exposure, practice, training, and education in order to achieve the potential implied in the high span.

Task Families

According to span theory, behavior can be classified into *task families*. Tasks within task families are *structurally* similar but vary greatly in type of stimuli and type of response (response topography). The word and digit recall tasks are exemplars of the immediate memory span task family. Other exemplars include: a) listening to a series of spoken words and speaking the series back, b) listening to a series of spoken words then writing them down, c) observing a series of color samples and reporting the colors in order, and d) listening to a teacher spell a word then repeating the letters or writing them down. Other task families include absolute judgment, span of apprehension, two-choice discrimination, operant conditioning, and classical conditioning.

Task Complexity

For each task family there is a complexity counting rule which is the principle which guides the estimation of complexity for a specific exemplar of the task family. For example, in immediate memory span tasks the complexity counting rule is: complexity is equal to the number of stimuli in the stimulus string. Task complexity is an important characteristic of tasks because one way to define span ability is that it is the ability to cope with task complexity. Higher span people cope with high complexity tasks fairly easily while lower span individuals cope adequately only with tasks of lower complexity. In general terms, span ability and task complexity interact to determine performance level. At lower levels of task complexity individual differences in span have little or no effect on performance. As complexity is increased, however, individual differences in span become increasingly important for predicting performance levels. At the higher complexity levels higher span subjects outperform lower span subjects.

Complexity/Performance Ogive

If relative performance is plotted against task complexity (for a variety of tasks) the resulting curve resembles a backwards S and is called a Performance X Complexity Ogive (PCO). See Figure 1.

Intelligence

Intelligence is the sum total of all acquired knowledge, behavior, and skills particularly as these are judged by our society to be desirable, functional, adaptive, and difficult. From this point of view intelligence is observable (or inferable) behavior. According to span theory, behavior (and, thus, intelligence) is a function of three major factors: experience, conditions at time of observation, and span ability. Those people with more or higher-quality experience are more intelligent because they have acquired more knowledge, behaviors, and skills. On the other hand, since acquisition rate is directly related to span ability, higher-span people will learn more in a given time and training period that will lower span people. But acquisition also depends on task characteristics. More-complex tasks are more difficult to learn than tasks of lower complexity. In fact, span ability and task complexity interact such that the importance of individual differences in span ability is minimal for tasks of lower complexity. As task complexity increases, however, individual differences in span ability become more and more important to the extent that on tasks of very high complexity, only those people with unusually high span abilities can perform and learn efficiently. These principles explain why higher-span people tend to be more intelligent people. The higher your span the easier it is to learn all tasks and in particular to learn the complex, cognitive tasks which are so important in our society.

Applications

One of the most important applications of span theory and task complexity analysis is simply to help clarify the complex nature of intelligence, complex human learning, retardation, cognition, language, and cognitive/intellectual development. The theory also is quite helpful in troubleshooting learning problems. Many times children fail to learn because the task or instruction method is too complex, that is, far enough beyond their span ability that their performance and acquisition rates are extremely low. Low performance leads to frustration on the part of both the student and the teacher. If it is determined that there is a mismatch between task and teaching demands and the student’s span ability then span theory and task complexity analysis can generally be used to develop new and effective teaching methods which match the student’s span ability.

In the process of educational goal setting span theory and task complexity analysis let one state goals which are within the reach of each student. Furthermore, it appears that the development of span ability is quite regular and simple so that it may be possible to extrapolate span abilities for individuals for specific future ages. Given this ability to predict future spans, task complexity analysis can be used to predict what skills and

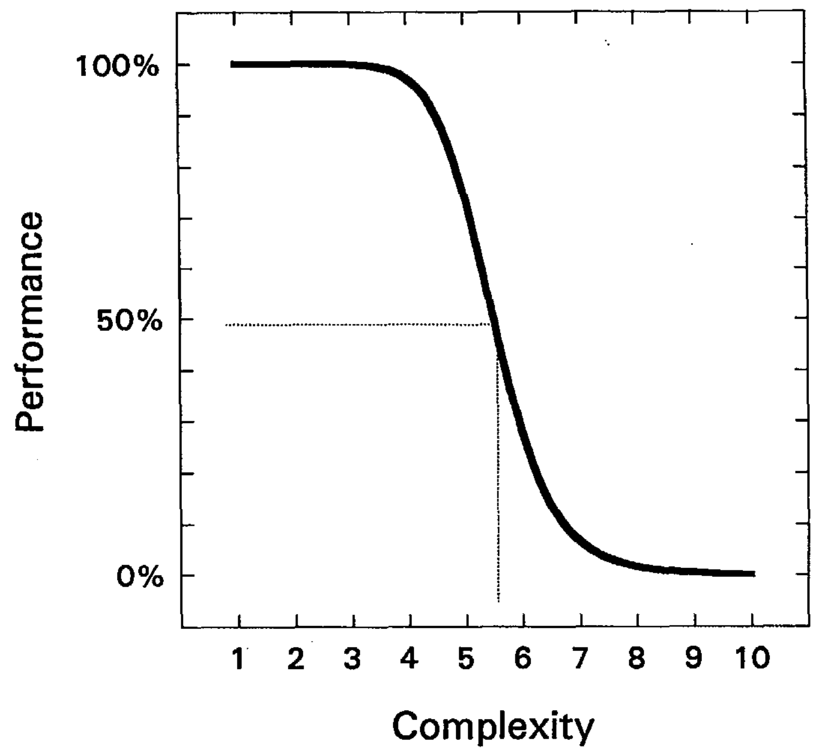

Figure 1. Performance X Complexity ogive. The dotted lines point out the 50% threshold, 5.5.

behaviors can be developed for each span level. It should be possible, then, to make meaningful specific projections of future potential (given proper education and training) for individual children and adults.

According to span theory, span ability is a very general ability, something like Spearman's *g*. It has also been shown that span ability is like Cattell's notion of fluid intelligence, G_f (Horn, 1968). This means that a span test measures a very basic aspect of intelligence and measures it free of specific learning experience. In other words, a span test may well be a culture-free test of an important aspect of cognitive ability. One application of this notion is to develop individualized span tests for people with atypical learning histories. For example, span tests for non-verbal, cerebral palsied, institutional adolescents have been developed and tested and shown to be effective and powerful predictors of language comprehension, language expression, and classroom learning (Bachelder, 1978). Research indicates that blacks score like whites on span tests (but tend to score low on IQ tests). It may be that span tests will help improve certain aspects of intelligence testing with minorities.

A GLOSSARY OF TERMS

Absolute Judgment: Absolute judgment is one of the basic prototypical tasks. In this task the subject sees stimuli varying along one dimension (such as size, color, pitch, loudness, brightness, etc.) and judges their relation to the other stimuli by assigning a number to each stimulus. Only one stimulus is present at a time and no feedback need be provided to ensure accurate judgments. Life examples include: looking at one of two sizes of bolts and accurately judging one to be the larger and the other to be the smaller. The counting rule is: Complexity is equal to the number of stimuli in the judgment pool.

Association: The relation between a stimulus and a response in an S-R bond is called an association. Stimuli tend to elicit or occasion their associated responses.

Counting Rule: A counting rule is a general statement which tells how complexity is determined for a family of tasks. For example, for the span tasks the complexity rule is: complexity is equal to the number of stimuli in a stimulus string. The counting rule for span of apprehension tasks is: complexity is equal to the number of stimuli per presentation. In the absolute judgment task the counting rule is: complexity is equal to the number of stimuli in a judgment pool.

Discriminative Stimulus: A discriminative stimulus is a stimulus which functions to specify for the organism when a response will be rewarded (successful, etc.). An "OPEN" sign on the door of a store is a discriminative stimulus telling a person that if he tries the door he will be able to enter and make a purchase.

Elementary Task: An Elementary Task is a task describable in generic terms which is also conceived to be unitary and elementary, that is, cannot be further analyzed into more elementary tasks. Some elementary tasks are the span task, the span of apprehension task, the absolute judgment task, the spatial location task, the classical conditioning task, the operant conditioning task, the two-choice discrimination task, and the conditional two-choice discrimination task. There are many others. Elementary tasks can combine to form more complex or *molecular* tasks.

Intelligence: Intelligence is the sum total of all acquired knowledge, behavior, and skills, particularly as these are judged by our society to be desirable, functional, adaptive, and difficult. From this point of view intelligence is observable (or inferable) behavior. According to span theory, behavior (intelligence) is a function of three major factors: experience, conditions at time of observation, and span ability. Those people with more or higher-quality experiences are more intelligent because they have acquired more knowledge, behaviors, and skills. On the other hand, since acquisition rate is directly related to span ability, higher-span people will learn more in a given time and training period than will lower-span people. But acquisition also depends upon task characteristics. More-complex tasks are more difficult to learn than tasks of lower complexity. In fact, span ability and task complexity interact such that the importance of individual differences in span ability is minimal for tasks of lower complexity. As task complexity increases, however, individual differences in span ability become more and more important to the extent that on tasks of very high complexity, only those people with unusually high span ability can perform and learn efficiently. These principles explain why higher span people tend to be the more intelligent. The higher your span the easier it is to learn all tasks and in particular to learn the complex, cognitive tasks which are so important in our society.

Life Analogue. A life analogue is approximately the same as a life example.

Life Example: All elementary tasks have exemplars in everyday life and classroom behavior. These every-day examples are called life examples as opposed to prototypical tasks or laboratory examples. Laboratory examples of prototypical tasks are rigidly defined and “artificial” while life examples are more variable and less rigidly defined. Laboratory examples can be fairly precisely understood while life examples are much less amenable to precise understanding and quantification.

Paradigm. Paradigm is a term used essentially interchangeably with the term task.

Prototypical Task: The term, prototypical task, is roughly synonymous with the term, elementary task. It is used when reference is made to an elementary task as a *prototype* for life examples of the task.

R: R is the symbol for a *response*.

Response: A response (R) is a theoretical construct referring to a bit of behavior which is observable, countable, and considered unitary. Examples include saying a word, writing a letter, reaching for a coin, pressing a button, etc.

S: S is the symbol for a *stimulus*.

Span Ability: Span Ability is the central concept of Span Theory. According to span theory, each person has a span ability which varies from person to person and which grows during the developmental period. Span ability is something like the concept of “g” in that it is considered to underlie individual differences in intelligence and learning. Those with higher spans will learn complex tasks easier than will those with lower spans. The span concept is used to explain the increase in mental ability during childhood and to explain individual differences in intelligence at all ages. Span Ability may be defined as the ability to cope with task complexity. In precise terms, span is the 50% threshold of the performance/complexity curve for the individual. See performance/complexity curve for an illustration.

Span of Apprehension. Span of apprehension is one of the basic prototypical tasks. The subject briefly views a random pattern of dots or any stimuli and responds with the number of items shown. The stimuli are presented rapidly enough that the subjects cannot “count” them in the usual sense of counting. The counting rule is: Complexity is equal to the number of stimuli per presentation. Life examples include: Glancing into a room and noting how many people are present and glancing at a bowl of fruit and seeing that there are just 2 apples there.

Span Task: The span task is one of the basic prototypical tasks. It consists of the presentation of a series of stimuli followed by the production of a series of responses. For example, the stimuli, *dog-cat-mouse* followed by the subject’s responses, “dog, cat, mouse.” Life examples include: hearing and repeating telephone numbers, listening to a teacher spell a word then spelling it back, listening to a teacher spell a word then writing it down (writing the letters is the series of response). The counting rule for the span task is: Complexity is equal to the number of stimuli in a stimulus string. The auditory-vocal word-span test (using common single-syllable nouns) is the standard clinical measure of span ability.

Span Theory: Span theory is a theory of intelligence and learning which posits that individual differences in intelligence and learning are due to a great extent to individual differences in span ability. Mental development during the developmental period is attributed to a great extent to maturation in span ability. Individual differences in intelligence and mental ability at any age are viewed as the result of individual differences in both span and learned skills and behaviors.

S-R Bond: The S-R bond is the symbol for the stimulus-response bond.

Staircase Span Test: The staircase span test is a test of span ability which is quite efficient in that it mainly tests performance on stimulus strings which bracket span ability. Little effort is wasted testing strings much above or much below span.

Stimulus: A stimulus (S) is a theoretical construct referring to objects, events, or responses which affect the behavior of an organism.

Stimulus-Response Bond: The stimulus-response (S-R) bond is a theoretical construct referring to the fact that the occurrence of certain stimuli tends to be statistically associated with the occurrence of certain responses. In other words, the construct refers to the fact that one can predict the occurrence of a response from knowledge of the occurrence of a stimulus. When an association is said to exist then the stimulus is said to elicit or occasion the response depending upon the theoretical predilection of the speaker or writer.

Symbol Board Span Test: A symbol board span test is a test of span ability which may be taken by a non-vocal individual. The subject listens for verbal word sequences of common nouns and points to them in order on a symbol board containing a set of from 5 to 10 pictures or symbols corresponding to each word.

Task Analysis: Task analysis is the process in which complex motor, verbal, and cognitive behavior is described in terms of stimuli, responses, S-R bonds, and response chains. The technique is useful in breaking difficult tasks into small units which are more easily learned by the retarded or young normal child. The technique is often useful because it stimulates us to describe teaching and training goals in objective measurable terms. It also tends to stimulate a new and more objective way to look at psycho-educational phenomena.

Task Complexity: Task Complexity is a central concept of Span Theory. According to the theory, all tasks have complexities measured in numbers ranging upwards from 0, usually in the range, 1 to 10. The theoretical definition of task complexity is the number of *jointly* or *conjunctively* relevant stimuli or cues in a task. In practice, complexities are determined by application of *counting rules* which differ for the various task families. For example, the counting rule for the span task is: complexity is equal to the number of stimuli in a stimulus string. Performance is an inverse function of task complexity. Put in other words, less complex tasks are easy and performance is high, higher complexity tasks are more difficult and performance is poor. Span theory presumes that performance is an inverse ogival (s-shaped) function of task complexity. See Performance/Complexity curve for an illustration.

Task Complexity Analysis: Task Complexity Analysis grew out of task analysis and differs, for the most part, in three ways:

1. A general individual differences psychometric construct is presumed, *span ability*.
2. The concept of the *response string* is added.
3. The response is not taken as the basic unit of behavior, rather, the *elementary task* is the basic unit of analysis.

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