The spans question: Challenges to the memory interpretation of the "memory" span test[1]

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Abstract

The spans question asks, ***What is the nature of the three span limits, the so-called memory span, span of apprehension, and span of absolute judgment?*** The memory interpretation of the "memory" span test has been dominant in recent years, but in the past 130 years other conceptions have been common. The spans question has been addressed by the major schools of thought, each framing an answer in terms of its own paradigmatic point of view. Most interpretations have been memorial or attentional, but there are neurological, learning, and stimulus control interpretations. The presentation ends with a brief characterization of span theory, a radical behavioral answer to the spans question.

The spans question asks, *What is the nature of the three span limits*? The curious span limits, each with a value of about 7, are sometimes called the "magical numbers," a term coined by George A. Miller (1956). The terms *memory span*, *span of apprehension*, and *span of absolute judgment* have been in common use, but there are other terms, each reflecting a particular paradigmatic or theoretical allegiance. Miller, for example, called them *limits on our ability to process information*. My own answer to the spans question is called *span theory* and it uses special terms, too. Today, I have time only for the so-called memory span test. For simplicity and theoretical neutrality, I'll just call it the span test.

The spans question is one of the oldest topics in experimental psychology and has roots in pre-scientific philosophy. As a research topic it has gone in and out of style for over 130 years. It has been addressed by philosophers, psychometricians, and experimentalists working within several schools of thought, including mentalism, structuralism, functionalism, behaviorism, and cognitive science. Some of our most prominent figures have addressed it, including William James, James McKeen Cattell, Francis Galton, Wilhelm Wundt, Arthur R. Jensen, and Alan Baddeley. It is the topic of Miller's (1956) magical number paper, the most famous paper in psychology, and one of the five documents which launched the cognitive revolution.

Figure 1 illustrates the three span limits. The figure plots probability of a perfectly correct total response as a function of the number of items in a stimulus set. Size of stimulus set is a potent independent variable. Performance with small sets is perfect or near perfect, but above 7 performance drops sharply to near 0.

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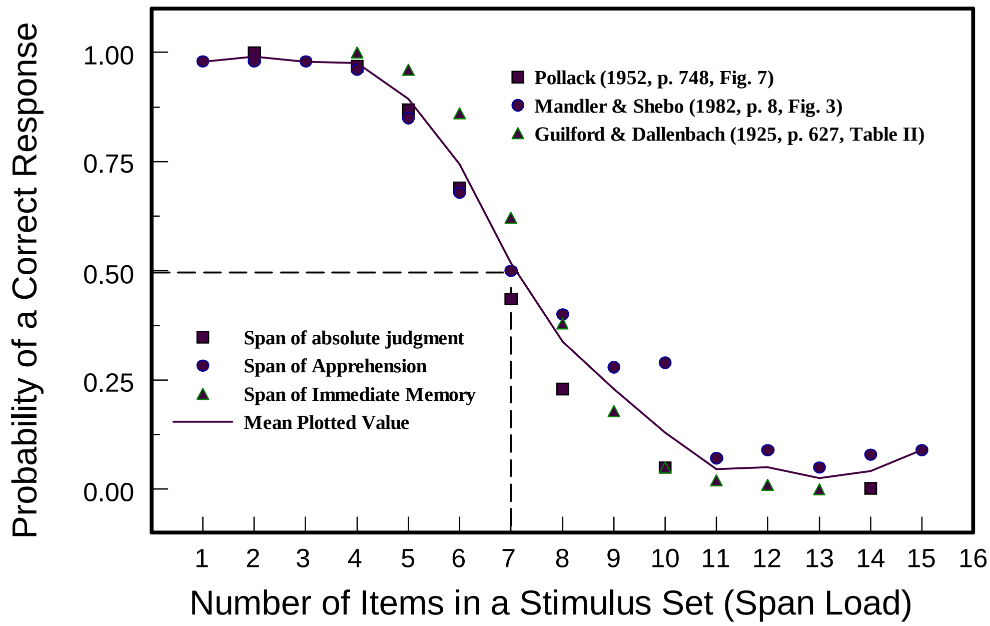

Figure 1. Performance in the three span tasks as a function of stimulus set size (span load)

These curves are based on group data, but individual curves resemble them closely. As an index of the span limit for an individual, span theory uses the 50% threshold of this curve. Measurement requires multiple trials testing subspan through supraspan stimulus sets, to estimate the probabilities of responding perfectly. From the results of that testing it is straightforward to derive a threshold score.

An example of a subspan, set-size 3 trial is "Chair-Tree-Home." An example of a supraspan, set-size 8 sequence is "Grass-Fish-Barn-School-Man-Tree-Chair-Dog." In all cases the participant attempts to reproduce the sequence exactly without reversals, omissions, or intrusions. A total response is recorded as either perfectly right or wrong.

To the layman this is a memory test. You hear the words, you remember the words, and you say them back. Your span is limited because you "forget." I looked at it differently in my dissertation (Bachelder, 1970/1971). I symbolized the memory span operation as follows:

$$S_1\ S_2\ .\ .\ .S_n{-}{-}{-}{-}{>}R_1\ R_2.\ .\ .R_n$$

I was working with M. Ray Denny from the point of view of his *elicitation theory* (Denny, 1966, 1967; 1986; Denny & Adelman, 1955; Denny & Ratner, 1970, pp. 12-16; Ratner & Denny, 1964, pp. 7-10; also see Estes, 1970, pp. 121-125; Marx & Cronan-Hillix, 1987, pp. 355-357) which is something of a hybrid of the Hull-Spence S-R learning theory tradition and the

Skinnerian radical behavioral tradition. We routinely analyzed behavior into S-R sequences and spoke of Ss as eliciting Rs. It was straightforward to view the so-called memory span as *elicitation span* in which S_1 elicits R_1, S_2 elicits R_2, and so on. I viewed the so-called memory span limit as a limit on the number of stimuli which can reliably elicit (or occasion) response sequences.

At the time, the late '60s, the span test was especially interesting to me for four reasons:

1) It had been known for at least 80 years (e.g. Galton, 1887) that people with mental retardation have smaller spans than normally developing children and adults. Span tests had long been used in IQ tests. The links with intelligence, the operational simplicity, and the extensive research literature made it an excellent "preparation" (Ratner, 1980) for the study of mental retardation and intelligence.

2) In 1964 my major professor, M. Ray Denny, published a literature review on learning and performance in people with mental retardation. He concluded they have four deficits bearing on acquisition of response repertoire: response inhibition, complex learning, verbal learning, and verbal control over motor behavior. The elicitation span deficit seemed to be a likely addition to Ray's list.

3) At an intuitive level an elicitation span deficit suggested a behavioral account of intelligence. We knew that people with retardation can learn when complex tasks are broken down into simpler S-R units. I hypothesized that lower-span people learn well when tasks are within their limited elicitation spans and higher-span people learn faster because they "take bigger bites" out of complex stimulus situations.

4) I knew that scientific discoveries are not about discovering new phenomena; discoveries are about new ways to view old and familiar phenomena (Kuhn, 1970, p. 85; Toulmin, 1953/1960, p. 17). Memory span and elicitation span are fundamentally different ways to look at the identical behavioral phenomenon; one is mentalistic, the other radical behavioral. Simply because it was different, the elicitation span interpretation was a candidate for being a *discovery*, the holy grail of science.

Those were exciting times. I had a dissertation topic, I had a good chance to elaborate on my major professor's contribution to mental retardation theory, and I was glimpsing a clash of titans, cognitivism versus behaviorism battling it out for dominance in the search for an understanding of intelligence, a topic that radical behaviorism had long neglected, minimized, proscribed, and often ridiculed as mentalistic.

Among the many things I didn't know as a graduate student is that scientists are not warm and encouraging in their reception of "neat new ideas." Scientists are especially conservative. Before they accept new points of view they ignore, then resist them (Barber, 1961; Kuhn, 1970, p. 64). William James (as cited by Troutner, 1969, pp. 124-125) also commented on the phenomenon with his "three classic stages of a theory's career." In the first stage it is attacked as absurd. It the second stage it is admitted to be true, but is considered obvious and insignificant. Finally, it is seen to be so important that its adversaries claim they themselves discovered it.

The publication of a maturing span theory (Bachelder & Denny, 1977a, b) and the occasional presentation at professional meetings have been received mainly with a deafening silence. But reactions have included encouragement, polite reservation, not so polite William James Stage 1 and Stage 2 reactions, and frustrating misunderstandings of span theory as just another memory theory.

Today, I'm trying a new strategy. I'm presenting an overview of the several reasonable ways the span limit has been viewed in the past 130 years. I want you to understand that span theory is not the only challenge to the memory interpretation of the span limit. Highly regarded figures have viewed it differently. Miller, himself, did not view it as memory. He viewed it as the capacity to transmit "chunks" of information.

Today's dominant point of view is Alan Baddeley's (1992) working memory theory. Stimulus items are converted to internal neurological representations and stored in STM. They immediately start to decay, but rehearsal refreshes the traces until the Central Executive uses them to produce the response sequence. Rehearsal takes time so at around 5 to 7 items rehearsal fails to keep up with time-based decay, errors begin to occur, and we observe the span limit.

Nelson Cowan (1988, 1999, 2001) has developed a variant of the working memory model which he calls "the embedded processes model of working memory." His model explains the span limit in terms of a capacity-limited *attentional* subsystem constraining the number of chunks which can be kept in mind at the same time. Interpretation in terms of attention is one of the earliest answers to the spans question, traceable at least as far back as Jacobs (1887), Cattell (1890), and Wundt (1912, in a popular version of his 1896 book).

Cowan's theory is a competitor, but it should be good for span theory. By challenging the conventional memory interpretation, Cowan has brought the spans question vigorously back into the literature. By reviving one of the earliest answers to the span question his work can help undermine the notion that memory is the only reasonable interpretation of the limit. Finally, in comparison with the memory interpretation, Cowan's cognitive, attentional model is much more like my behavioral, stimulus control point of view. The similarity suggests a bridge between cognitivism and radical behaviorism.

Baddeley's and Cowan's two cognitive science theories parallel the state of affairs about 120 years ago when memorial and attentional points of view competed and mingled. Hermann Ebbinghaus (1885/1913) interpreted the span limit as a memory limit. Joseph Jacobs (1886, p. 53) referred to the span limit as a memory limit, but the very next year (1887, p. 79) he asserted an attentional conception. He called it "*prehension*. . . the mind's power of *taking on* certain material." To James McKeen Cattell (1890) the span test assesses *both* attention and memory. Wilhelm Wundt (1912, p. 31) spoke of the limit as "the maximum of simple impressions that can be grasped by attention." The 1912 book is a popularization of his 1896 book.

Lightner Witmer (1902, p. 59) characterized the span limit as "the number of discrete perceptions . . . [which] can be associated in a single act or grasp of attention." Humpstone

(1917, p. 16; 1918-1919, pp. 196, 197) adopted Witmer's conceptualization, emphasized ***associability***, and argued (1918-1919, pp. 196, 197) that span tests are not tests of memory. Leaming (1922, p. 200), in a variation of Witmer's conception which is reminiscent of Cowan's working memory notion, wrote that the span limits "measure the number of discrete units over which the individual can successfully distribute his attention and still organize them into a working unit." Skerrett (1922, p. 221) referred to the span limit as "the number of units comprehended by the span of attention."

Gundlach, Rothschild, & Young (1927, p. 278) preferred the term ***complexity of set*** over ***memory***. Johnson (1955/1971) combined the notions of attention and set. He characterized the span limit as "a unit of attention" (p. 81) and "the number of disparate items that one can attend to or think about or ***get set*** [emphasis added] to deal with in any way during any one moment" (p. 82). These notions of the span limit as a limit on set are interesting because they seem to be cognitive analogues of an early span theory conception (Bachelder & Denny, 1977a, b) that the span limit reflects a limitation of the ability to cope with complex stimulus control.

Hilgard (1951, p. 547) argued the span limit does not assess the span of attention or the span of apprehension, but measures the number of items which can be ***learned*** in one trial. Peterson (1963, p. 351) suggested that viewing "memory" span in terms of learning would be fruitful. Staats & Staats (1964, p. 176) suggested that "the source of the child's 'memory span' for words consists of the skilled vocal responses and the various associations between (sequences of) these responses."

There are quasi neurological explanations of the span limit. Ellis (1963, p. 134) viewed the limit in terms of the Hullian construct, stimulus trace. One of the most intriguing answers to the spans question has been advanced by Weisman (1986, p. 257). He characterized the span limit as the quantum number of a brain understood as a macroscopic quantum oscillator. As a radical behaviorist of the old school I avoid neurological speculation. I haven't even tried to evaluate the evidence for Weisman's idea but Weisman's interpretation bears exploration.

Alfred Binet (1909, as cited by Starr, 1923, p. 72), even though he used a span test on the very first and subsequent intelligence tests, considered it to measure, not intelligence, but the "capacity for effort." More recently, Matarazzo (1972, as cited by Hunt, 1978, p. 117) asserted something similar. He considered span tests to measure the "ability to perform tasks requiring concentrated effort."

Many interpretations over the years put the span limit at the very center of intelligence. Blankenship (1938, p. 17) in a review of the literature, listed several papers which put "memory span ability at the base of all intellection." Such conceptions occurred very early on. Physician and author, Oliver Wendell Holmes (1871, p. 33, as cited by Dempster, 1981, p. 66), suggested that the memory span test might serve as a "mental dynamometer." that is, an instrument to measure the power of the mind. Joseph Jacobs (1887, p. 79) recommended the span test be used as one of the "tests of mental capacity." Wilhelm Wundt (1912) considered the two processes, apprehension and apperception (indexed by a span test), together to ". . . form the whole of our psychical life" (p. 42).

There are more recent publications which put the span limit(s) at the core of conceptions of intelligence. Horn (1968, p. 249, Table 1) cited a factor analysis which indicates the span test measures *fluid intelligence,* but not *crystallized intelligence.* Arthur R. Jensen (1970, p. 73) characterized the span limit as an almost pure measure of Level I ability, an associative intelligence which he contrasted with Level II, ability, a cognitive intelligence. IQ tests reflect a combination of Level I and Level II intelligences. Arguably, Miller's (1956) channel capacity hypothesis falls into this category. Staats (1968, pp. 405-406), a behaviorist, acknowledged the span limit could reflect a biological capacity limitation, but he focussed on a learning explanation.

Span theory puts the span limit at the center of behavioral notions of intelligence. Bachelder (1970/1971) hypothesized that a limited *elicitation span* accounts for limitations in acquisition of intellectual repertoires among people with mental retardation. Bachelder & Denny (1977a, pp. 135-137) interpreted the span limit as a limitation of the capacity to cope with complex stimulus control. Stimulus complexity was defined as the number of stimuli conjunctively relevant for a target response. Developmental and individual differences in this capacity interact with experience to produce the behavioral repertoires we call intelligence.

Span theory in its current state (unpublished) has advanced a good bit over Bachelder (1970/1971) and Bachelder & Denny (1977a, b). Instead of the *response* or the S-R bond, the *task* is taken to be the fundamental unit of theoretical analysis. A task is a generic concept, that is, a task is a family of tasks varying in details such as the specific stimuli and responses. For example, digit span tests and word span tests are in the same task family. A task is characterized in terms of its *procedure,* its *counting rule,* and its *task equation.* The procedure is a description of the task with an aim to replication. It is essentially the same as the *Procedures* sections in journal articles. The counting rule specifies the way *span load* is counted (*span load* replaces *stimulus complexity* used by Bachelder & Denny, 1977a, b). In Figure 1 the counting rule for all three tasks is: Span load is equal to the number of items in a stimulus set. The *task equation* specifies the mathematical relation between performance and span load. Figure 1 shows that for all three span tasks the task equation is: Performance is an inverse ogival function of span load.

In span theory the three span tasks are called *Span of sufficient Stimuli* (SoS), *Span of Numerosity* (SoN), and *Span of relative Magnitude* (SoM). SoS, SoN, and SoM refer fairly closely to the tasks referred to by the traditional terms, *memory span*, *span of apprehension*, and *span of absolute judgment*, respectively. The three span tasks are considered *elementary* tasks which comprise the building blocks of complex tasks. *Task Analysis of Span Load* (*TASL;* pronounced "tassel") is the process by which complex tasks are analyzed and modeled in terms of elementary tasks. TASL is an elaboration on the behavioral technique of task analysis. TASL has been brought to bear on both basic (e.g. Bachelder, 2000) and applied (e.g. Bachelder, 1978, part 3; Bachelder, 2003) research topics. Span theory bridges cognitivism and behaviorism by bringing cognitive *tasks* but not mentalism to a radical behavioral analysis.

In closing, let me summarize. Instead of pleading the merits of span theory in a David and Goliath confrontation, I have aimed to alert you that there is a horse race here. The memory interpretation is no more nor less than one paradigmatic strategic working assumption in the

Kuhnian sense. There are other reasonable ways to look at things. The stakes are high. The spans question deserves your engagement. In the spirit of Thomas S. Kuhn, may the most fruitful point of view prevail!

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