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THE COMPARATIVE PSYCHOLOGY OF CHUNKING

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The ability to learn arbitrary sequences is crucial for intelligent action, both verbal and non-verbal. For more than a century, psychologists have investigated the organization of such sequences in experiments on the memorization of nonsense syllables (Ebbinghaus, 1964) and the mastery of various types of mazes (Small, 1900). The results of both types of experiment gave rise the classic theory that serially organized behavior can be represented as a linear sequence of associations.

Ebbinghaus explained list learning by reference to associations between successive items and between a particular item and its list position. Hull offered a similar explanation of maze learning by rats (Hull, 1952). Thus, associative principles that were used to explain how a human adult memorizes a list of arbitrary items were used to explain how an experimentally naive rat learns a sequence of arbitrary responses, and vice versa (Osgood, 1953; Underwood, 1957).

After dominating psychological thinking for more than half a century, the validity of association theories of serially organized behavior was questioned on a variety of theoretical and empirical grounds (Lashley, 1951; Chomsky, 1957). In his classic analysis of serially organized behavior, Lashley rejected linear models because they could not explain knowledge of relationships between non-adjacent items (for example, between words before and after an embedded clause) and because inter-response times

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between successive responses are often shorter than the time that would be needed for feedback from one response to trigger the next (for example, playing a sequence of notes on a musical instrument). These and related arguments have been described in detail by others and will not be elaborated in this chapter (e.g., Anderson & Bower, 1974; Gardner, 1985). Instead our focus will be the concept of chunking (Miller, 1956), one of the most influential but, as we shall see, one of the most poorly understood concepts of modern cognitive psychology.

The significance of chunking derives from its ability to overcome objections to linear models of serially organized behavior association by augmenting linear structures with hierarchical structures. Although the concept of chunking was proposed to define the capacity of short-term memory, it has also been used to characterize such diverse phenomena as long-term memory, visual perception, and motor plans. The main purpose of this chapter is twofold: to examine some problems that arise when the concept of chunking is used uncritically and to distinguish between two basically different types of chunks: *input* and *output* chunks.

George Miller introduced the concept of chunking in his classic paper, "On the magical number 7 ± 2" (1956). Miller argued that a chunk was the basic unit for measuring the capacity of immediate memory [in current terminology, *short-term* or *working* memory; see Baddeley (1992) for a discussion of the taxonomy of different memory systems]. The idea was that subjects could retain a large number of discrete items of information if they were encoded as chunks before they were transferred to long-term memory. For example, the 12 digits 1-4-9-2-1-7-7-6-1-8-1-2 could be encoded as 3 historical dates. In contrast to the enormous capacity of *long-term memory* (LTM), Miller estimated the capacity of STM to be 7 ± 2 chunks and argued that the amount of information that is retained in STM is independent of the amount of information contained by each chunk.

The facilitory effect of chunking on human memory has been confirmed by a broad variety of experiments. Familiar examples include the enhancement of recall on lists on which subjects can assign items to verbally defined categories (Bousfield & Bousfield, 1966; Bower, 1972a) and on lists composed of temporally defined clusters of items (Bower & Winzenz, 1969). On a conceptual level, chunking is regarded as a basic cognitive process despite differences between theorists as to the functional and anatomical boundaries of STM and LTM (Atkinson & Shiffrin, 1971; Baddeley, 1981; Craik & Tulving, 1975; Mishkin & Petri, 1984; Squire, 1986; Weiskrantz, 1970), the types of evidence that have been used to distinguish STM and LTM (Bower, 1972b; Estes, 1972; Johnson, 1972; Murdock, 1993) and the actual capacity of STM (Broadbent, 1975; Crowder, 1976; Mandler & Dean, 1969; Wickelgren, 1964, 1967).