III

Psychophysics of Memory

Guest Editorial

Nelson Cowan
University of Missouri, Columbia

Writing an essay on the psychophysics of memory is like clearing a doorway in a wall separating adjoining apartments inhabited by Gustav Fechner (1801–1887) and Hermann Ebbinghaus (1850–1909) or, given that they actually lived in different cities, perhaps like installing network connectivity between them. Fechner had the idea of examining the relation between the physical world and the psychological effects that result from our experiencing that world; Ebbinghaus had the idea of tracing the diminishing availability of some psychological effects over time (Boring, 1957). Put them together, and you get the concept of exploring the nature of the effects of physical stimuli that persist following the disappearance of the actual stimuli. There were fundamental similarities between Fechner and Ebbinghaus that could assist in this union. For example, both men grasped the potential of systematic research on the human mind and both understood the need to develop research methods that could deal with considerable trial-to-trial variability.

I would like to consider a possible taxonomy of the psychophysics of memory and ask which parts of it pertain to the following chapters. There actually are at least two ways in which psychophysics and memory can interact. First, in what could be called *memory endurance*, the physical stimulus can cause a sense impression, and the sense impression can result in a memory trace or representation of the stimulus. Then the integrity and accessibility of the trace can be queried at a later point in time. As a trace is partly forgotten, there may be several subcategories under memory endurance. The trace may change over time in its *veridicality*, or adherence to the original percept; in its *precision*, or level of completeness; and in it *accessibility*, or conditions necessary to evoke the memory again.

Second, in what could be called *memory influence*, a preexisting memory can influence the perceptual effect that a stimulus elicits when it is first presented. For example, if one has never before seen even a picture of an elephant, one's next encounter with a real elephant will evoke quite a different (more emotionally intense, yet confusing) psychological effect than if one is familiar with elephants. Let me define two subtypes of memory influence. There can be a *remote* influence from well-learned information or there can be a *local* influence from immediately preceding stimuli.

Most, though not all, of the evidence presented in the excellent chapters within this section of the book relates to what I have broadly termed memory endurance. Bredenkamp (chap. 14, this volume) presents a mathematical model that describes short-term memory in terms of bits or features of each item, the capacity for those features, and the time it takes to search through those features. However, underneath this surface another important question lurks: the question of how we know the composition of an item that determines its retention. Bredenkamp specifies items in terms of their presumed informativeness in bits but, ordinarily at least, we must consider how preexisting learning affects how new information is encoded; in present terms, we must consider memory influence.

Miller's (1956) famous article suggested that people typically can recall approximately seven items in serial order, but that does not imply that seven independent chunks are retained; the items may have been grouped into a smaller number of chunks, as he also described. I (Cowan, 2001) suggested looking at situations in which the items are familiar to begin with and in which grouping of these familiar items into higher-level chunks is prevented in one way or another. A wide variety of such situations showed that adult humans could recall approximately 4 items in such situations, which presumably reflected only four chunks. However, I am currently looking for ways to extend our understanding to the more typical situation in which it is difficult to know how the material is chunked. In many situations, chunks may not even exist. Instead, there can be sets of items that are too strongly associated to be considered independent chunks, yet too weakly associated to be considered a single chunk. What is needed as a first start toward relating intermediate levels of association between items to capacity is a psychophysical type of mapping between the history or strength of associations between items (memory influence) and the amount of a limited-capacity focus of attention that is taken up by the items (memory endurance).

Kaernbach (chap. 15, this volume) examines whether the types of short-term memory described as *sensory* and *categorical* may actually operate according to closely analogous mechanisms, as I (Cowan, 1988) suggested. Sensory memory refers to memory of how an item appears to the senses and categorical memory refers to the meaning it has. However, both may be carried by activated circuits within a larger long-term memory network. Kaernbach's investigation focuses on the two main ways in which a memory representation can become inaccessible: through the passage of time, or *decay*, and through displacement by, or interference from, other memory representations. In the latter case, one can ask whether the memory representations could be displaced by any other representations or only by others that are very similar in nature. If the interference is rather general and depends on the number of items in total that are being held in a readily accessible form at once, that is basically what is commonly meant by a *capacity* limit, which Kaernbach discusses. In the present taxonomy, the paper deals primarily with memory endurance generally and memory accessibility specifically (i.e., what elements are retained or lost). However, if a multisegment stream of noise is taken to be a unit in memory and some segments are lost in memory, then memory for the multisegment stream can be said to suffer a loss of precision, too.

Lass, Lüer, Becker, Fang, and Chen (chap. 16, this volume) cover the relation between encoded items and the mechanisms that allow memory representations of these items to be retrieved shortly afterward. What is under study is the speeds of various mnemonic processes. There appear to be two types of processes whose speeds enter into recall separately: rehearsal processes, emphasized in the most prominent theory of short-term or working memory (Baddeley, 1986), and retrieval processes, as suggested by Cowan et al. (1998) to supplement rehearsal. This work emphasizes a careful examination of the processes that take place after the initial sensory encoding of items and therefore seems to focus on memory endurance generally, and memory accessibility specifically.

The final two papers in the series can be said to combine both memory endurance and memory influence. Roeber and Kaernbach (chap. 17, this volume) show how a memory-search function does not depend much on rehearsal and does not have a fixed limit in terms of how many items can be searched; the slope function flattens out gradually. This is taken as support for the notion of a large pool of activated, rather accessible representations of items persisting after the presentation of a stimulus set. Thus the memory endurance from list item presentations provides a local memory influence on a following test probe item presentation.

Schröger, Tervaniemi, and Huotilainen (chap. 18, this volume) examine the properties of auditory sensory memory and its endurance, but they also suggest that there is a long-term or remote memory influence on auditory sensory memory from previous, attended discrimination learning sessions that use those stimuli.

The work that has been discussed primarily deals with what information is remembered or forgotten. It does not deal much with how information is distorted or, in present terms, memory veridicality. Of course, false memories are a hot topic in cognitive psychology today, and some of the recent research on false memories is even related to sensory factors (Gallo, McDerbott, Percer, & Roediger, 2001; Kellogg, 2001). More specifically related to psychophysics, though, is a small area termed *memory psychophysics* (e.g., Algom, 1992; Hubbard, 1994; Petrusic, Baranski, & Kennedy, 1998). Research from that area shows that the basic laws of psychophysics, such as Stevens' power law, are preserved when one must recall, rather than presently experiencing, the stimuli to be judged. However, they are preserved with a change in exponents; there is compression of the range of judged intensities. Bright lights when remembered do not seem quite as bright as they did when they were actually presented, and so on. In relying on persisting memories of events there is not only a loss of memory precision, but also a loss of veridicality. In a similar vein, Cowan and Morse (1986) found that memory of a cardinal vowel not only becomes less precise but also seems to slide toward a more neutral vowel representation as it is forgotten in the seconds following its presentation.

The taxonomy that I have suggested is just a first approximation. For one thing, unstated by the taxonomy, veridicality of the percept may depend on memory influence. For example, an uninterrupted short auditory memory trace of a brief sound is needed to reach the full intensity of the auditory percept (Cowan, 1987).

As yet, there is not much integration between the methods used in sensory psychophysics and memory. For example, Miller (1956) brought up absolute identification of items as a psychophysical method and pointed out a limit in how many unidimensional stimuli can be included in the set of items to be identified; approximately six or seven, a severe informational capacity limit. The research in memory psychophysics has used similar techniques but seems to keep the number of stimuli to be identified under the capacity limit, so that the problems of long-term memory of the percepts to be judged and short-term memory of the categories assigned to these items do not affect the results simultaneously. It would seem that there is still much to be gained from studies in which a standard set of experimental procedures is applied to the joint exploration of psychophysics and memory.

ACKNOWLEDGMENTS

This chapter was written with support from grant R01 HD-21338 from the National Institutes of Health. I thank jeffrey Rouder for discussions on the method of absolute identification.

REFERENCES

Algom, D. (1992). Memory psychophysics: An examination of its perceptual and cognitive prospects. In D. Algom (Ed.), *Psychophysical approaches to cognition* (Advances in Psychology No. 92, pp. 444–513). Amserdam: North-Holland.

Baddeley, A. D. (1986). *Working memory* (Oxford Psychology Series No. 11). Oxford: Clarendon Press.

Boring, E. G. (1957). *A history of experimental psychology* (2nd ed.). Englewood Cliffs, NJ: Prentice-Hall.

Cowan, N. (1987). Auditory sensory storage in relation to the growth of sensation and acoustic information extraction. *Journal of Experimental Psychology: Human Perception and Performance, 13*, 204–215.

Cowan, N. (1988). Evolving conceptions of memory storage, selective attention, and their mutual constraints within the human information processing system. *Psychological Bulletin, 104*, 163–191.

Cowan, N. (2001). The magical number 4 in short-term memory: A reconsideration of mental storage capacity. *Behavioral and Brain Sciences, 24*, 87–185.

Cowan, N., & Morse, P. A. (1986). The use of auditory and phonetic memory in vowel discrimination. *Journal of the Acoustical Society of America, 79*, 500–507.

Cowan, N., Wood, N. L., Wood, P. K., Keller, T. A., Nugent, L. D., & Keller, C. V. (1998). Two separate verbal processing rates contributing to short-term memory span. *Journal of Experimental Psychology: General, 127*, 141–160.

Gallo, D. A., McDerbott, K. B., Percer, J. M., & Roediger, H. L., III. (2001). Modality effects in false recall and false recognition. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 27*, 339–353.

Hubbard, T. L. (1994). Memory psychophysics. *Psychological Research, 56*, 237–250.

Kellogg, R. T. (2001). Presentation modality and mode of recall in verbal false memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 27*, 913–919.

Miller, G. A. (1956). The magical number seven, plus or minus two: Some limits on our capacity for processing information. *Psychological Review, 63*, 81–97.

Petrusic, W. M., Baranski, J. V., & Kennedy, R. (1998). Similarity comparisons with remembered and perceived magnitudes: Memory psychophysics and fundamental measurement. *Memory & Cognition, 26*, 1041–1055.