THEORIES AND METHODS OF MEMORY PSYCHOPHYSICS: LINKS TO COGNITIVE PSYCHOLOGY

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Abstract

The focus of research in memory psychophysics has moved from a preoccupation with magnitude scaling to studying response times and information processing. The need for integrating these research traditions is stressed.

The idea that memory is sustained by images formed on the basis on the original sensations can be traced back to Plato and Aristotle. The same notion resonated with pioneers of psychophysics in the nineteenth century. Fechner's little read article from 1882 is titled, "Some thoughts on the psychophysical representations of memories." Tichener, in his 1906 classic, *An outline of Psychology*, held the strong view that memory obeys Weber's law. And, the work of both Wundt and Ebbinghaus is informed by the perceptual study of memory. Despite its roots in antiquity and at the birth of modern psychology, memory psychophysics, or mnemophysics (Algom & Marks, 1989) is a young field of inquiry. Juvenility notwithstanding, the field already boasts a somewhat convoluted history, as the center of interest has moved from valuation and scaling to modeling through information processing. Below I sketch this development, then pinpoint several problems awaiting resolution in future research.

Memory Psychophysics through Scaling

Memory psychophysics or mnemophysics (Algom & Marks, 1989) is the branch of psychophysics that treats the functional relationship between physical stimuli and their remembered sensory responses. It was 1978 that ushered in this conception of the discipline of memory psychophysics. Two independent studies were published in prestigious journals (Kerst & Howard, 1978; Moyer, Bradley, Sorensen, Whiting, & Mansfield, 1978) entailing the derivation of psychophysical functions for remembered stimuli. Moyer et al had participants magnitude estimate the size of various stimuli that were either presented physically (perceptual estimation) or represented symbolically by names that the participants had learned earlier to associate with the various stimuli (memorial estimation). Two experiments, one in odor (Algom & Cain, 1991) and another in taste (Algom & Marks, 1989) used the same methods to derive psychophysical functions for perception and memory for common sets of referent stimuli.

In our experiments, a striking feature of each pair of functions was the excellent fit by a power relationship (all sets of data approximated straight lines in double logarithmic coordinates). Especially notable was the reappearance of the power function in memory, implying that remembered stimuli map onto physical values the same way – by the same mathematical rule – as perceived stimuli do. These results support the view that mental processes of memory and imagery mirror processes of perception given the same task and stimulus characteristics. Preliminary theories have been offered to elucidate the exact values of the respective pairs of exponents (the memorial exponent usually smaller than the perceptual one, cf. Algom 1992). On a more general level, the results of these studies treating a single physical continuum suggest the existence of lawful and long-enduring constraints on knowledge about perceptual experience (Shepard, 1984; Wolf & Algom, 1987).

Two problems affect mnemophysical research with univariate designs, one methodological, the other substantive. First, Stevens's (1975) contention that the numbers proffered by participants, whether perceptually or from memory, are proportional to sensation magnitudes can not be justified. Consequently, the validity of the method of magnitude estimation and the associated power law is suspect. The need for an underlying metric structure to support validity is as vital for memory psychophysics as indeed it is for the entire edifice of psychophysics. For the second problem, the purview of univariate research is limited. It is ill suited to examine questions of organization and integration in memory. Multidimensional mnemophysics, in contrast, aids in resolving both problems. First, memory psychophysics applied to factorial designs erected on multidimensional stimuli – rectangles, chemical mixtures, combinations of painful stimuli – does provide the metric structure needed for authenticating the overt numerical response. The rules by which the components integrate, uncovered by methods such as conjoint measurement or functional measurement, provide constraints to validate the psychophysical function. Specification of the model of integration already entails the scale as its natural derivative. Second, deployment of multivariate mnemophysics enables the examination of a new class of questions dealing with stimulus construction in memory. In particular, the constancy (or lack thereof) in form of stimulus integration in perception and memory can be assessed (Wolf & Algom, 1987). Further intriguing problems can be tackled, an example of which comes from the domain of chemosensation.

For homomodal chemosensory mixtures, that is, for mixtures of tastants alone and for mixtures of odorants alone, a salient characteristic is mutual masking of components or mixture suppression. An odor mixture or a taste mixture will smell or taste less intense than the sum of the perceived intensities of its unmixed constituents. An interactive pattern of mixture perception (and memory) ensues. In contradistinction, when humans are stimulated with heteromodal mixtures, comprising and odorant and a tastant, the olfactory and taste systems behave in an additive manner. The overall intensity of odor-taste mixtures approximates the simple sum of the intensities of the unmixed components. Which rule do *mental mixtures* of odor and taste follow? In that condition, participants are presented with orally sensed tastants and odorants separately (i.e., no physical mixtures are presented). Their task is to mentally mix the components, then estimate the intensity of the resulting mental mixtures. Algom, Marks, and Cain (1993) took advantage of a compelling illusion by which observers misperceive orally presented odors as tastes. Odor and taste stimulate two modalities (hence the additive structure for physical mixtures), but to the naïve observer mixtures of an odorant and a tastant in the mouth are recognized erroneously as taste mixtures (hence the possibility of an interactive structure based on illusory homomodality). Strikingly, an additive structure reappeared in the mental-mixture condition, despite the fact that the participants believed they were mixing mentally two tastes. The evidence for the pervasiveness of a chemosensory "deep knowledge" seems impressive. People display far deeper sensory knowledge than they are either aware of or can intelligently articulate.

Memory Psychophysics through Information Processing

The framework of scaling, especially single-variable scaling, has been inhospitable to explicating the processing of information associated with symbolic stimuli. Magnitude estimation as well as other nonspeeded scaling measures do not fit well with a nascent cognitive science dominated by measures of reaction time and dynamic modeling. Indeed, a notable feature of information-processing-based models of memory psychophysics is their full alliance with mainstream cognitive psychology. Reaction time and rate of error replace magnitude estimated and scaling in this research. This research allows for the examination of a richer class of phenomena including learning, decision, and representation. The common mental process of comparing a pair of stimuli has been studied intensively within the information processing tradition. I first recount major phenomena associated with symbolic comparisons, then describe three attempts to model them from an information processing perspective.

Deciding which numeral in the pair, 8-2, is larger numerically, or deciding which name in the pair, cat-dog, refers to the larger animal, is based on symbols standing for the referent stimuli, and necessarily entails information retrieved from memory. The symbolic *distance effect* documents the decrease in response time as the difference between the referent stimuli is increased, mirroring the perceptual relation by which reaction time is inversely related to stimulus difference. The *end effect* pertains to the fact that pairs of stimuli containing the smallest or the largest stimulus are compared fastest. Finally, the *semantic congruity effect* documents the interaction of pair size and experimental instruction by which large pairs are compared faster under 'choose the larger stimulus' instruction and small pairs are compared faster under 'choose the smaller stimulus' instruction.

Link's (1975; Link & Heath, 1975) Relative Judgment Theory postulates that the psychological value of a stimulus is compared, through subtraction, against the psychological value of a standard stimulus (a mental standard is established whether or not the experimenter actually uses a standard stimulus). The process entails sequential sampling in small windows of time of the random variables representing the stimulus and the standard, then deriving their momentary difference. The random variable of the sum of these differences performs a random walk on the psychological dimension of comparative difference -- the distance between two response thresholds ("dog is larger than cat," and "dog is smaller than cat"). During an experimental trial, the differences are accumulated until one or the other of the two response thresholds is exceeded.

Choice response time is proportional to the amount of accumulated differences divided by the rate of accumulating the differences. This simple formula is modified by subtracting or adding a bias constant to the accumulated differences, and by adding a constant to the entire formula standing for nondecisional factors contributing to reaction time. Regarding the distance effect, the model includes a discriminability parameter that is monotonically related to stimulus difference. The drift rate also changes with stimulus difference. The larger the subjective difference the fewer is the number of samples needed to reach threshold. Response time thus decreases, producing the distance effect. The end effect is explained by response bias, a result of biased stimulus designs. For instance, given an extremely small stimulus, the probability approaches 1 that the comparison stimulus is larger. The probability for "larger" responses increases with a concomitant decrease in response time. The semantic congruity effect is simple response bias produced by the instructions, "choose larger" or "choose smaller." These bias the starting point of the random walk toward one of the thresholds, shifting the point (toward small or large stimulus difference) at which the maximum response time occurs. Indeed, Link (1990) questions the very phenomenon of semantic congruity, "There seems to be little value in creating yet another name to describe experimental results due to response bias" (p. 36). Links notes correctly that standard depictions of the effect of semantic congruity fail to account or even to mention the concomitant changes in response probability.

Petrusic's (1992) Slow- and Fast-Guessing Theory is another sequential-sampling model envisaging a discrete-state evidence accrual process. Accumulated is (1) information favoring the overt response, "dog is larger than cat," (2) information favoring the overt response, "cat is larger than dog," and (3) information favoring the overt response, "dog is as large as cat." Each kind of information is accumulated with a fixed probability to a pre-set criterion. On a trial, information is accumulated in discrete steps until one of these criteria is achieved. Because no overt response is afforded for the third kind of information, the participant guesses either response (1) or response (2) once the criterion for (3) is passed. The criterion is under the participant's control, its setting sensitive to the experimental demands. Stressing accuracy results in higher setting of the criterion (slow guessing): Long response times, but high accuracy is predicted. Stressing speed results in low setting of the criterion (fast guessing): Fast reaction times but high rates of error ensue. An appealing feature of the theory is the rich set of speed-accuracy tradeoff functions predicted at different levels of processing under a variety of experimental conditions.

The distance effect is treated in the theory by a discriminability parameter, a function of the probabilities for the different kinds of information, themselves a function of comparative difficulty. The end effect is not directly addressed in the theory. Regarding the effect of semantic congruity, it is assumed that the effect occurs at the level of each evidence accrual event. However, no explanation is offered why large pairs are judged faster under "choose larger" instructions and small pairs are judged faster -- in each sample of evidence accrual.

Finally, a comprehensive model of response time developed recently by Leth-Steensten and Marley (2000) includes a connectionist learning phase simulating the association of symbols to stimuli. Although pairs of adjacent stimuli only are presented for learning, entailing ordinal information with respect to their relative position on the referent continuum, analog-valued representations are derived for all stimuli. Notably, these representations already entail the distance and end effects as a natural emergent property of the network derived on the basis of routine associative learning. The semantic congruity effect, by contrast, is not an emergent property of the set of representations. A computational version of the linguistic conflict between stimulus size and direction of the comparative instruction is introduced to account for the effect.

Questions and Challenges

Recall the *raison d'etre* for the emergence of the discipline of memory psychophyics: To explicating the difference between perceptual and remembered judgments made to a common set of physical stimuli. This fundamental distinction is often overlooked in the information approach (but see, Petrusic, Baranski, & Kennedy, 1998). Link's (1992) wave theory refers to discriminations between the art of Caravaggio and Titian and to discriminations between pairs of weights on the same footing. The theory does not include features that treat possible differences in processing between physical and symbolic comparisons. How does one compare the numbers 2 and 7 on numerical magnitude as opposed to, say, comparing two lines on length? As mere physical stimuli, 2 is neither larger nor smaller 7. S. S. Stevens had noted that in many a situation numerals simply comprise ink marks on a piece of paper. To compare the numerals (but not the lines!), people must retrieve the referent magnitudes. Once they are retrieved, the comparison may well obey the principles developed in Link's theory. However, it is precisely the need for symbolic processing and its implications that lie at the heart of memory psychophysics.

Petrusic's theory does appreciate the difference between perceptual and symbolic comparisons. However, it denies any substantive variance in processing between the two; the latter simply is more difficult, hence requiring more samples to reach response criteria. The larger number of samples in memorial comparisons augments the memorial effects, notably that of semantic congruity. The model developed by Leth-Steensten and Marley also recognizes possible differences between perceptual and memorial comparisons, but it only treats the latter. Integrating scaling and information approaches to memory psychophysics remains a challenge to be met in future research.

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