Smythe (*9*) report that color is not a variable that is significant for the recall of either pictures or words. Meanwhile, it has been demonstrated, with both human subjects and monkeys (*10*), that discrimination learning is more efficient for three-dimensional objects as compared to flat patterns.

The assumption that stimulus abstractness is inversely related to the amount of information in the stimulus display suggests that subjects should recall objects with the greatest frequency, pictures with the next greatest frequency, and words with the least frequency throughout the period of free recall. A random selection was made of the response sheets of 30 of our subjects: 5 adults and 5 children from the subgroups tested immediately after the initial presentation of the stimulus response, 5 adults and 5 children from the 24-hour subgroups, and 5 adults and 5 children from the 1-week subgroups. A tabulation was made of the kind of stimuli identified on successive responses. As their initial response, 12 of the 30 subjects mentioned an object, 11 a picture, and 7 a word. This rank order of object-picture-word tended to manifest itself with occasional variation throughout the entire series of responses. For example, on the sixth response, 12 subjects responded with objects, 5 with pictures, and 4 with an object name. The subjects not only tended to respond with objects but these responses also tended to persist as other forms of response dropped out. Thus by the 12th response, two subjects responded with objects, one with a picture, and all other responses were exhausted. Only one subject gave as many as 14 responses, and his last response identified an object. In other words, the relative strength of responsive modes tended to display itself early and to persist throughout the response period. This pattern evidenced itself with equal clarity in the immediate, 24-hour, and 1-week recall data.

Although the stimulus encoding hypothesis is attractive, we cannot, at this point, eliminate the possibility that objects, and to lesser extent pictures, have greater motivating properties than words as stimuli for recall. At the same time that they are more distinct they are also more interesting and vivid.

The superiority of adult performance over that of children (Fig. 1) was confirmed by statistical test [between age groups: $F(1, 513) = 28.52$, $P < .001$]. However, the responses of the two age groups to the several versions of stimuli differed with time of recall [time of test: $F(26, 513) = 14.91$, $P < .001$]. Further analysis indicated that there were initially only slight differences between adults and children in the recall of objects and these had disappeared by the time of the 1-week recall test (difference between age groups at 1 week $= .20$, least significant difference at .05 level $= .25$). In contrast, adults were clearly superior to children in their recall of pictures throughout all test periods. Finally, the anticipated superiority of adults in the recall of words did not assert itself until there had been a 1-week delay in recall (difference between age groups at 1 week $= 1.51$, least significant difference at .05 level $= .25$).

Bruner (*11*) has described the representation of past experience in memory as involving different modes, depending on the individual's level of cognitive development. Memory at the earliest stage of life is characterized by the enactive mode, that is, by the retrieval of past events through appropriate motor responses. Later on, the child is capable of the iconic mode, that is, the ability to organize and use images as the vehicle of retrieval. The last mode to appear is the symbolic mode in which language or some similarly abstract coding system is used to represent experience. Psychologists have been aware of these modes for some time and in describing them have been inclined to view one or the other as dominant at a particular age with the further important assumption that the others were undeveloped, unused, or alternatively deteriorated. Thus, whereas children use images, adults use language, and these different modes represent characteristically different cognitive styles.

Our results suggest a rather different interpretation. Adult behavior is more versatile than that of the child not simply because the adult has a more versatile cognitive style in his well-developed language skills but because he has a richer, and probably more thoroughly integrated, repertory of multiple cognitive modes. Indeed, he appears to do as well as the child in handling the iconic mode, that is, his recall of objects appears to be as good as, if not better than, that of the child. The adult's clear superiority in the recall of pictures is consistent with Paivio's hypothesis that he has integrated iconic and symbolic modes.

WILLIAM BEVAN

Department of Psychology, Johns Hopkins University, Baltimore, Maryland 21218

JOSEPH A. STEGER

Department of Psychology, State University of New York at Albany, Albany 12205

References and Notes

1. A. Paivio, *Psychol. Rev.* **76**, 241 (1969); see also *ibid.*, pp. 254–256.
2. E. Tulving and S. A. Madigan, *Annu. Rev. Psychol.* **21**, 437 (1970); see also *ibid.*, pp. 451–453.
3. H. C. Fryer, *Concepts and Methods of Experimental Statistics* (Allyn & Bacon, Boston, 1966).
4. H. Helson, *Adaptation-Level Theory* (Harper & Row, New York, 1964), p. 228; E. J. Gibson, *Principles of Perceptual Learning and Development* (Appleton-Century-Crofts, New York, 1969), pp. 152–154.
5. H. Helson, *Psychol. Rev.* **55**, 297 (1948).
6. C. W. Eriksen and H. W. Hake, *J. Exp. Psychol.* **50**, 155 (1955).
7. K. G. Scott, *J. Verb. Learning Verb. Behav.* **6**, 864 (1967).
8. M. Posner, in *The Psychology of Learning and Motivation*, G. H. Bower and J. T. Spence, Eds. (Academic Press, New York, 1969), pp. 44–100.
9. A. Paivo, T. B. Rogers, P. C. Smythe, *Psychonom. Sci.* **11**, 137 (1968).
10. H. F. Harlow, *J. Gen. Psychol.* **32**, 213 (1948); H. W. Stevenson and G. McBee, *J. Comp. Physiol. Psychol.* **51**, 752 (1958).
11. J. S. Bruner, *Amer. Psychol.* **19**, 1 (1964).
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Differential Cerebral Processing of Noise and Verbal Stimuli

Abstract. *Psychophysiological measurements have indicated that the right cerebral hemisphere processes noises and other nonverbal data and that the left cerebral hemisphere processes verbal material. Direct physiological measurements, as expressed in summated auditory evoked cortical responses, unequivocally demonstrate that click noises show a greater amplitude of initial output over the right brain, and that verbal stimuli produce either equal or higher amplitudes of output over the left cerebral hemisphere.*

By the psychophysiological technique of simultaneous application of different auditory stimuli to the two ears, Kimura (*1*) showed that the left brain had a predilection for processing verbal symbols and that melodic or nonverbal symbols were processed predominantly by the right cerebral hemisphere (*2*).

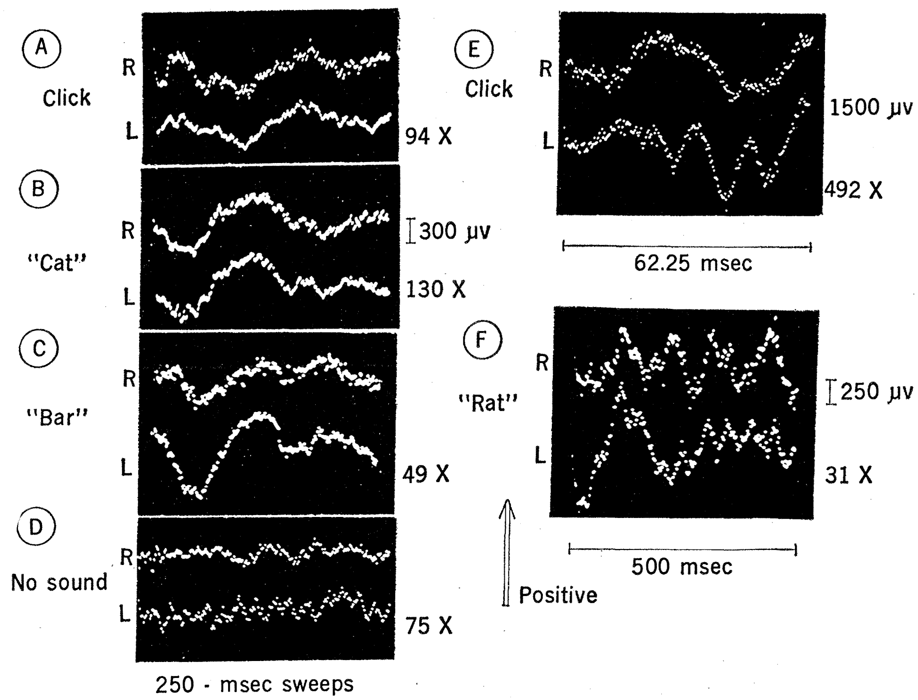

Fig. 1. (A) Characteristic right brain and left brain responses to clicks. Note the initial short latency positive deflection over the right side. (B) Summated cortical evoked responses to single-syllable word stimuli ("cat"). (C) Another pair of summated responses to verbal stimuli ("bar"). (D) Control. Summed cortical activity with no applied auditory stimuli. (E) Cortical responses to noise; expanded time base. (F) Responses to verbal stimuli ("rat") on compressed time base. The numbers (such as 94 ×) to the right of each pair of waves represents the number of stimulus presentations. Positive is indicated by an up-going deflection. Calibrations are in microvolts (*5*).

To confirm these findings by direct physiological methods, noise and verbal symbols were successively applied to both ears, and the summated auditory evoked cortical responses, which were simultaneously obtained from each cerebral hemisphere, were recorded.

The two types of auditory stimuli used in the present study were (i) a 10-msec square wave pulse that generated a loud click in earphones placed in the external auditory canals, and (ii) single syllable words that had a decrementing duration of approximately 150 msec. The verbal stimuli triggered the sweep of the Computer of Average Transients (CAT 400A) by means of a voice-operated relay and a pulse generator. The stimuli were presented at a rate of approximately one per second. One derivation electrode of each homologous pair was placed 2 cm anterior to the external acoustic meatus, and the other was placed in a vertical coronal plane 2 cm from the midsagittal line. The electrodes were solder disks, which were applied to the scalp with a conducting paste and fixed in position by collodion. The amplifiers had overall time constants of 0.4 second; they were matched for all significant characteristics. The amplified signals were summated by a CAT 400A computer. The summed potentials were photographed from the scope face.

To the click stimuli, 37 subjects with clinically normal auditory acuity all showed the basic characteristics demonstrated in Fig. 1A, which consisted of a prominent positive-going peak with a latency of around 14 msec in the right brain derivation. Contemporaneously in the summated output of the left brain, a complex-formed, notched, or multiphasic wave, generally of lower amplitude and somewhat delayed, was observed.

In approximately one-half of the subjects a second positive peak occurred, which had a corresponding peak on the left side. These initial deflections were usually followed by a negative inflection, which in turn was succeeded by a long positive peaked wave, with an average peak latency of around 175 msec. The form and timing of the simultaneously recorded initial deflections are shown to advantage in the expanded time base of Fig. 1E. The apparent initial positive deflection in the left-sided output of Fig. 1E was the result of spontaneous electroencephalographic activity, as it varied in successive summations, whereas the major deflections remained invariant.

Verbal stimuli such as "cat" and "bar" generated summated cortical outputs of the type seen in Fig. 1, B and C. An initial almost synchronous negativity characterized these evoked responses. The initial negative deflection varied in time of occurrence, but the first inflection ranged between 30 and 50 msec. The succeeding positive waves generally showed almost synchronous peaking at around 125 msec. Twenty individuals showed approximately equal amplitudes of summated evoked cortical responses over the two sides to the verbal stimuli. Seventeen subjects showed a greater amplitude of output over the left brain when presented with verbal stimuli. This latter phenomenon is shown in Fig. 1, C and F; Fig. 1F

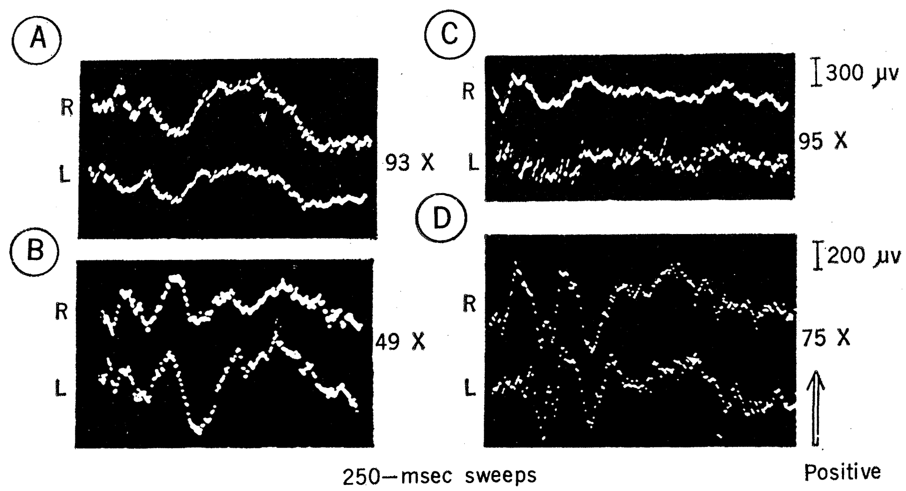

Fig. 2. Click responses from four different, randomly chosen subjects, which demonstrate the reproducibility of the right-sided initial deflection.

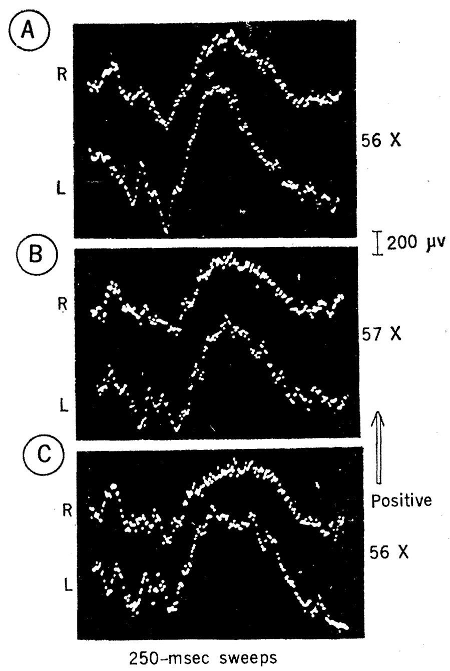

Fig. 3. Three successive summated cortical responses to click in one subject. The biological invariance of the short latency initial inflection on the right side is shown.

is on a compressed time scale. As a control, in nearly all tests the conditions of the experiment were maintained, except that no noise or specific sound was used to trigger the CAT sweep. At these times the general picture of Fig. 1D was obtained.

The potential patterns of four randomly chosen subjects to whom click stimuli were presented are shown in Fig. 2; this figure demonstrates the almost invariant character of the initial, approximately 14 msec inflection from the right brain. It is observed that the secondary oscillations and the positive peaks vary considerably.

The stability of the right-sided initial response to clicks in three successive summated responses in a single individual is shown in Fig. 3. Although the initial responses from the left brain vary, the 14 msec right brain responses remain biologically invariant.

Four subjects in this series were predominantly left-handed; their summated cortical evoked responses were similar in all ways to the preponderantly right-handed persons.

If it is allowed that the amplitude of summated evoked cortical responses is directly related to the site of predominant processing of the auditory signals, then it seems indisputable from these physiological data that noises (clicks) are initially processed primarily in the right brain. Again, if the above reasonable assumption is accepted, single-syllable words are processed in each cerebral hemisphere equally in approximately half of the subjects studied; in the other half of the subjects, however, the left brain shows a dominance for verbal processing.

From studies in the visual system (*3*) it would appear that the wave-form differences observed between clicks and words might be the consequence of the variable primary stimuli used; but the consistent differences in amplitudes and contours over the two hemispheres, as seen in this auditory work, were never evident in full field illumination, irrespective of the quality of visual stimuli employed.

Such differential cerebral processing of the auditory input as described is not unique. Recently it has been shown that in the visual system (*4*) there is a difference in right brain and left brain processing of language and nonlanguage data as determined by material derived from averaged evoked responses from each occiput.

An obvious extension of this auditory work for operational clinical purposes will be the introduction of precision sources of phonetic input.

This physiological study generally confirms, and somewhat furthers, the psychophysiological work of Kimura.

ROBERT COHN*

U.S. Naval Hospital,
Bethesda, Maryland 20014

References and Notes

1. D. Kimura, *Cortex* **3**, 163 (1967).
2. D. Kimura and S. Folb, *Science* **161**, 395 (1968).
3. R. Cohn, *Brain Res.* **4**, 292 (1967).
4. M. Buchsbaum and P. Fedio, *Physiol. Behav.* **5**, 207 (1970).
5. The amplitude calibrations were made by impressing a known voltage square wave through the entire system, and recording the single sweep output from the CAT face. This method obviates the variance effect of the subjects' successive inputs. The primary biological signals were calculated to be in the range of 3.5 to 3.75 µv.

* Present address: 5530 Wisconsin Avenue, Chevy Chase, Maryland 20015.

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Acetylcholine Liberation from Cerebral Cortex during Paradoxical (REM) Sleep

Abstract. *The rate of liberation of free acetylcholine from the surface of prostigmin-treated cerebral cortex in the freely moving cat has been determined in states of slow wave sleep, paradoxical or activated sleep, and waking. The average rate during slow wave sleep (1.2 nanograms per minute per square centimeter of cortical surface) increased during paradoxical sleep (2.2 nanograms per minute) and during waking (2.1 nanograms per minute). The rate of acetylcholine release is thus related to the electroencephalogram pattern of desynchronized activation of the cortex rather than to the behavioral responsiveness of the animals.*

The rate of liberation of acetylcholine (ACh) from the surface of the cerebral cortex treated with an anticholinesterase may be increased two to three times when an animal is awakened from natural slow wave sleep by normal sensory stimulation or by electrical stimulation of the midbrain reticular system (**1**). These observations, confirmed in other laboratories (*2*), have led to the conclusion that the desynchronized activation of the cerebral cortex which characterizes the electroencephalogram (EEG) during states of alertness or arousal from slow wave sleep (SWS) may be cholinergic at the cortical level, even though other neurochemical transmitter substances may be involved as well in the mediation of states of sleep and wakefulness at subcortical levels, such as the monoamines (*3*).

There is, however, another state of deep sleep which is characterized by desynchronized activation of the electrical activity of the cerebral cortex similar to that seen in waking and alertness. This has been called paradoxical sleep (PS) because the animal (or man) appears to be deeply asleep and even more relaxed than in SWS, whereas the EEG resembles that of a state of alertness. There are also characteristic rapid eye movements which suggested the designation REM sleep. There remains to be determined whether the rate of ACh liberation from cerebral cortex is increased during PS, as in wakefulness, after the appearance of the EEG, or whether it