5. G. Erdtman, *An Introduction to Pollen Analysis* (Chronica Botanica, Waltham, Mass., 1943), p. 178.
6. K. Maunsell, in *Progress in Allergy*, P. Kallos, Ed. (Little, Brown, Boston, 1955), vol. 4, p. 457.
7. S. M. Greenfield, *J. Meteorol.* **14**, 115 (1957).
8. W. M. Sharp and H. C. Chisman, *Ecology* **42**, 365 (1961).
9. This report was prepared in the course of work done with support of the Office of Naval Research, Contract Nonr 2173(03). Helpful comments of Dr. Paul S. Martin, Geochronology Laboratory, University of Arizona, are gratefully acknowledged.

12 July 1961

Stabilization of Behavior and Prolonged Exposure to Delayed Auditory Feedback

Abstract. The disruption of fluent verbal behavior found under delayed feedback is replaced by stable patterns when presentation is prolonged. Experimental analysis suggests that the later patterns involve the reinstatement of control by stimuli in whose presence the behavior was originally established.

The auditory or visual stimuli produced by speaking or writing need not occur immediately, as is normally the case, but may be presented to a subject after a brief delay. The reported result is a disruption of behavior (*1*). In such experiments, subjects are typically run for short sessions. When subjects were required to read aloud for extended periods of time, however, nonfluencies produced by delayed auditory feedback (delayed "sidetone") disappeared (*2*). New speech patterns emerged, which suggested that some of the disruptions reported may be transient phenomena. For example, an initial stutterer avoided blocks or arrhythmias by slowing his rate of reading to six words per minute (*3*). The verbal response "then came John" can be represented in relation to its delayed auditory stimulus to the speaker in this way:

R: ð ɛ ɛ ɛ . . . ɛ ɛ n
S: ð ɛ ɛ . . . ɛ ɛ ɛ n
R: K e e e . . . e e ĭ m
S: K e e . . . e e e ĭ m
R: d ʒ ɑ ɑ ɑ . . . ɑ ɑ n
S: d ʒ ɑ ɑ . . . ɑ ɑ ɑ n

During normal speech, response and stimulus overlap in time. By stretching out each word, the speaker can reinstate the normal overlap, for the medial part of each word, at least. Beginnings and ends of words still display the asynchrony produced by delayed feedback. By increasing the proportion of medial to bounding units, the speaker increases the similarity between normal and delayed feedback. Others solved the problem of delayed feedback without slowing down. Some lowered their voices; others "spat out" the words or read without normal inflection. These results can also be interpreted as ways of restoring "normal" conditions. Verbal behavior produces stimuli other than those carried by air. These may be bone-conducted stimuli, or laryngeal, labial, and other proprioceptive stimuli from the vocal apparatus, and these may not be altered by the delayed sidetone. By lowering his voice, the speaker may increase the relative importance of the normal feedback. In contrast to prolongation, however, the reinstatement is of nonauditory stimulus control. Again, the absence of normal inflections in some subjects may mean that, stated intuitively, the speaker may not be listening to himself. This possibility has been studied in the following way.

Normally fluent college students read continuously from a novel for 90 minutes each day for several weeks. Each subject spoke into a microphone and heard himself through matched Telephonic TDH-39 earphones. An Ampex 601 delivered normal sidetone, at an intensity level judged sufficient to overcome bone conduction for each subject. An Echo-Vox Senior was matched in volume, and provided for adjustable delay. Every tenth word read was recorded by a monitor and transmitted to cumulative recorders and digital counters. When reading rate was stable, varying periods of delayed and normal sidetone were introduced and maintained until the reading rate recovered. Then, for periods of 10 minutes, started and terminated by auditory signals, the subjects were instructed to read as rapidly as possible and either (i) not to listen or (ii) to listen to their reading.

Figure 1 shows words read per minute during such consecutive periods by two subjects, listening or not listening, as instructed, and with sidetone normal or delayed (*4*). The reading rate tends to be low for "delay-listening" conditions and higher for the other three conditions: "delay-nonlistening," "normal sidetone-listening," and "normal-nonlistening." For subject B, day 1, the first range was 163 to 196 words per minute; the second was 217 to 261 words per minute. On day 2, the ranges were 185 to 194, and 231 to 256. Subject G showed ranges of 206 to 209, and 214 to 232. On 2 days, the highest rates were under *delay* conditions (period 6 for subject B on day 1, and period 4 for subject G).

These data support the assumptions that verbal behavior is under control of stimuli produced by preceding responses, and that one method of maintaining the behavior under new conditions is to reinstate some fraction of earlier conditions (*5*), including tem-

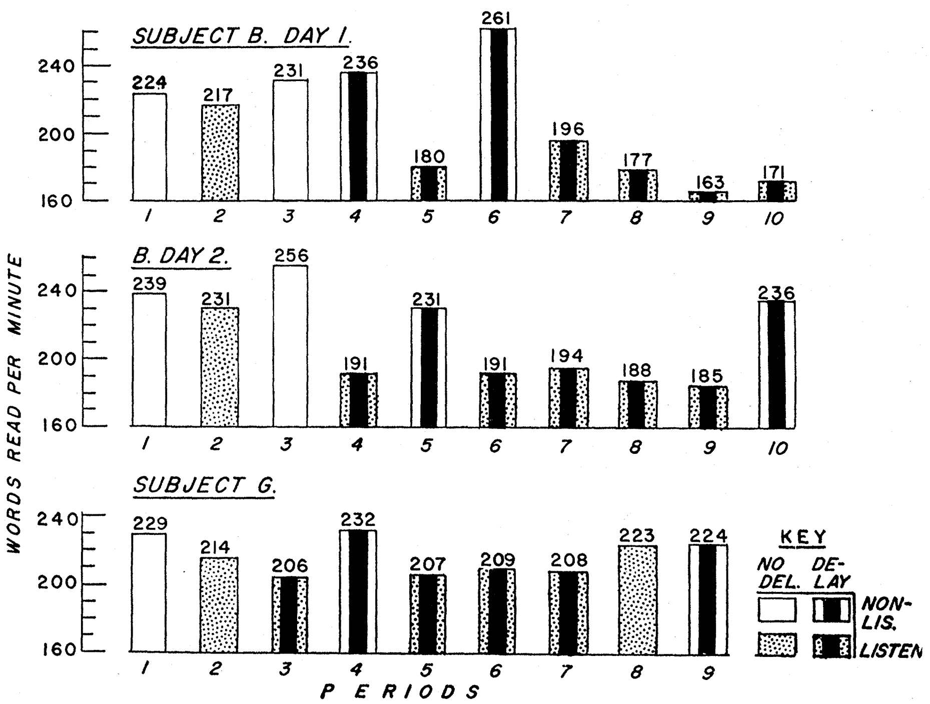

Fig. 1. Reading rate as a function of normal and delayed sidetone, when subject is under instructions to listen and not to listen.

poral overlap between verbal responses and the stimuli contingent upon them. Under normal sidetone, this overlap is present whether the subject is instructed to listen or not to listen. It may also be present when the subject is speaking under delayed sidetone and is instructed not to listen, since such instructions may facilitate control by nonauditory stimuli which overlap the responses. When, however, the non-overlap is auditory (delay) and the subject is instructed to listen to it, the similarity to normal overlap conditions is minimized. This may account for the high reading rates under the first three conditions, and the low rates under the fourth condition displayed in Fig. 1.

A stimulus which maintains the strength of a response when contingent upon it is reinforcing. Reinforcement is maximal when it is immediate. The auditory stimulus is generally contingent upon a verbal response in this sense (*6*). In the typical operant conditioning experiment, the experimenter controls such stimuli; the stimuli in verbal behavior, however, are under control of the speaker, or self-controlled. Delayed feedback separates these stimuli from the responses and may bring them under the control of the experimenter. Their role in maintaining behavior can thus be analyzed experimentally (*7*). Delayed feedback may prove a useful tool not only for experimental analysis and control, but also in identifying the stimuli that maintain continually ongoing behaviors, of which verbal behavior is one example (*8*).

ISRAEL GOLDIAMOND
Arizona State University, Tempe
CHESTER J. ATKINSON
Southern Illinois University, Carbondale
ROBERT C. BILGER
Medical School, University of Pittsburgh, Pittsburgh, Pennsylvania

References and Notes

1. J. W. Black, *J. Speech Hearing Disorders* **20**, 65 (1955); G. Fairbanks, *ibid.* **20**, 333 (1955); W. M. Smith, J. W. McCrary, K. U. Smith, *Science* **132**, 1013 (1960).
2. I. Goldiamond, *Air Force Command and Control Development Div. Tech. Rept. No. 60–38* (1960); *J. Mathetics*, in press.
3. The stutterer mentioned was on an avoidance schedule during which delayed feedback was present continuously, except when he stuttered. This turned off the delay and presented normal feedback for 10 seconds. The prolongation pattern was accompanied by virtually no stuttering, hence the delayed feedback was practically continuous throughout the session. Where delayed feedback was presented continuously without being contingent upon responses of the speaker, a stutterer reacted as did the normally fluent subjects: an initial lowering in reading rate, followed by recovery. Details are reported by Goldiamond (*2*).
4. The amounts of delay used were 200, 300, and 400 msec. No functional relations were discovered between these amounts and reading rates during the sessions.
5. This is considered as "consistent with maintaining a 'normal' experience at the ear" by J. W. Black (*1*).
6. The reinforcing stimulus can also serve as a discriminative stimulus which controls the next response as well as reinforcing the preceding class of responses, a process called chaining. See F. S. Keller and W. N. Schoenfeld, *Principles of Psychology* (Appleton-Century-Crofts, New York, 1950); B. F. Skinner, *Verbal Behavior* (Appleton-Century-Crofts, New York, 1957); J. G. Holland and B. F. Skinner, *The Analysis of Behavior* (McGraw-Hill, New York, 1961).
7. This issue is considered in greater detail by I. Goldiamond, "Perception," in *Experimental Foundations of Clinical Psychology*, A. Bachrach, Ed. (Basic Books, New York, in press).
8. The research described in this report was sponsored by the Operational Applications Laboratory, Air Force Command and Control Development Division, Air Research and Development Command, under contract No. AF 19 (604)-6127. This report is identified as AFCCDD TR-60-38.

18 September 1961

On the Increase of Sites for Chromosome Exchange Formation after Chromosome Duplication

Abstract. Although radiation-induced chromosome exchanges are not distributed among cells according to a Poisson distribution, chromatid interchanges are. In *Vicia faba* the lack of fit to a Poisson distribution has been attributed to the occurrence of only two sites per cell where the chromosomes are close enough to form exchanges if broken. When chromatid aberrations are induced, after chromosomal duplication, the number of sites more than doubles.

One of the most common and significant effects of radiation on biological systems is the nuclear damage manifested as chromosome aberrations. According to the most widely accepted theoretical explanation of the induction of such aberrations, the radiation first breaks the chromosomes, and the broken ends then rejoin in new configurations that are frequently visible at metaphase.

Although most chromosome aberrations are distributed among cells according to a Poisson distribution, indicating that breaks occur at random (*1*), cases of nonrandomness have been reported (*2*). In particular, the chromosome exchanges that are induced before the chromosome duplicates do not fit such a distribution (*3*). This is contrary to the results observed for chromatid interchanges (induced after chromosome duplication) in *Tradescantia* microspores (see *1*). The nonrandom distribution of chromosome exchanges in *Vicia faba* lateral roots, *Tradescantia* microspores, and *Hordeum* seeds is characterized by the occurrence of too few cells having multiple exchanges (*3, 4*).

This lack of randomness is attributed to the occurrence of a limited number of places within the nucleus where the strands of the chromosomes would lie close enough to one another to rejoin if broken (*4*). Lea originally calculated this rejoining distance, called h, to be 1 μ, but more recent calculations by Wolff (*3*) and Wolff, Atwood *et al.* (*4*) indicate that this distance is less than 0.3 μ and is probably about 0.2 μ. If there were a large number of sites where the chromosomes come within h microns of one another by chance, more cells would be expected to have multiple exchanges and the aberrations would be distributed randomly. Atwood and Wolff's calculations have shown that the average number of sites per cell for *Vicia* root tip cells is two or less, and the average number for *Tradescantia* microspores is four (*5*). Furthermore, the chromosome exchange aberrations are distributed among the cells according to the binomial distribution of

$$[p + (1 - p)]^n \qquad (1)$$

where p is the probability of obtaining an exchange in a site and n is the number of sites in the cell.

There were four such sites in the *Tradescantia* microspore nucleus before chromosomal duplication, and after duplication one might expect this number of sites to increase. If the number of sites as much as doubled after chromosome duplication, it would be impossible to distinguish between a binomial and a Poisson distribution of aberrations (because it is extremely difficult to score cells with excessive chromosomal damage accurately), and the binomial distribution for a large number of sites would approximate a Poisson distribution. In *Vicia* root tip cells, however, which have only two such sites before chromosome duplication, if the number of sites doubled to become four, then it would be possible to distinguish between the two types of distributions.

The experiments reported here were undertaken to determine the magnitude of the increase in the number of sites which occurs after chromosomal duplication.

Inflorescences of *Tradescantia paludosa* were collected, placed in waxed containers with spring water, and irradiated in air with 120 r of x-rays at