albumin (*4*). It is notable that this cyclostome and certain elasmobranchs have no albumin-like component in their plasma, while teleosts in general appear to possess such an albumin-like component (*5*).

DAVID P. RALL
PAUL SCHWAB
CHARLES G. ZUBROD
National Cancer Institute, National Institutes of Health, Bethesda, Maryland

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10 October 1960

Test of Response Bias Explanation of Word-Frequency Effect

Abstract. Observers identified monosyllabic words presented in noise. It was found that controlling response bias eliminates the word-frequency effect. However, the magnitude of the word-frequency effect was greater than that predicted by a mathematical model denying stimulus words any role in producing the word-frequency effect.

The word-frequency effect refers to the finding that observers faced with the task of identifying words presented in noise or flashed briefly on a screen identify correctly more common words than uncommon words. The more common a word is (the more frequently a word occurs in the language), the greater is the probability that the word will be identified correctly (*1*).

The response bias explanation, in its most general form, denies stimulus words any role in producing the word-frequency effect. The word-frequency effect is considered to be due merely to response bias—the observer's tendency to use more words of high word-frequency as identifying responses than words of low word-frequency (*2*).

We interpret this form of response bias explanation as implying that groups of words which differ in word-frequency are random samples from the same population of acoustical or visual parameters. In other words, response bias explanation seems to imply that intervals of word-frequency which contain the same number of words are equivalent samples. Consequently, if there are n intervals, a stimulus word from one interval may be matched, in terms of physical similarity, just as adequately by a response word from one as from another of the remaining $n-1$ intervals.

The word-frequency effect may be derived if we take the assumption of acoustical equivalence of intervals as implying two mathematical relations:

$$p_c(s,r) = kp(s,r), \qquad s = r \qquad (1)$$

where s and r indicate the interval of the stimulus word and the response word respectively; $p(s,r)$ is the probability of a particular combination of stimulus interval and response interval, given that s equals r; $p_c(s,r)$ is the proportion of $p(s,r)$ for which the response word is correct; and k is a constant between zero and unity. This equation may be interpreted as saying that when the stimulus word and the response word are in the same interval, the probability that the response is correct is independent of the interval of the stimulus.

$$p(s,r) = bp(r) + d, \qquad s \neq r \qquad (2)$$

where $p(s,r)$ is the probability of a particular combination of stimulus interval and response interval given that s is not equal to r; $p(r)$ is the probability of a response in a particular interval; and b and d are constants. This equation is mathematically equivalent to saying that a response from a particular interval will be given just as often to words from one (different) interval as to words from another (different) interval. Equation 2 further implies that

$$p(s,r) = \frac{1}{n}\,p(r) + a, \qquad s = r \quad (3a)$$

$$= \frac{1}{n}\,p(r) - \frac{a}{(n-1)}, \qquad s \neq r \quad (3b)$$

where n is the number of stimulus or response intervals and a is a constant. Thus, Eq. 2 mathematically determines all of the n^2 probabilities of combinations of stimulus interval and response interval to within one constant, when the $p(r)$ values are known and $p(s)$ is a constant ($1/n$). Together Eqs. 1 and 2 imply that the number of words in an interval which are correctly identified is a linear function of the number of responses in the interval. That is,

$$p_c(s,r) = k\left[\frac{1}{n}\,p(r) + a\right], \qquad s = r \qquad (4)$$

Thus, the word-frequency effect is derived in terms of $p(r)$—$p(r)$ supposedly being some monotonic function of the median word-frequency of the interval. The word-frequency effect, from the viewpoint of Eq. 4, must increase with a rate of k/n. In this sense, the magnitude of the word-frequency effect is predicted from Eqs. 1 and 2.

The above equations assume that $p(s)$ is a constant and that the intervals all contain the same number of different words in the language. In general, the equations assume that no physical aspect of words related to the threshold changes from interval to interval. Word length must be controlled since it has been shown to be positively related to intelligibility (*3*). This can be approximated by limiting stimulus and response words to words of the same number of syllables.

To test the predictions of Eqs. 1 and 4 an experiment was conducted at two speech-to-noise (S/N) ratios, 0 and +10 db. These S/N ratios resulted in an over-all probability of correct response of 0.13 and 0.68, respectively. A different group of six observers listened at each S/N ratio. Words were presented at a rate of approximately one every 10 seconds. Each observer listened for

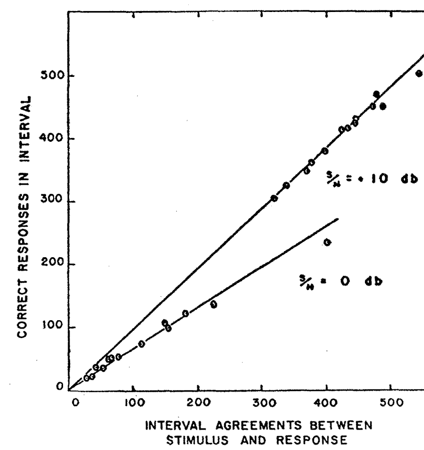

Fig. 1. Number of correct responses in an interval as a function of the number of instances where stimulus and response agree in interval [$p_c(s,r)$ versus $p(s,r)$]. In general, the greater the number of agreements, the greater the median word-frequency of the interval. The points, one for each interval, represent the sum of the data for the six observers in the group.

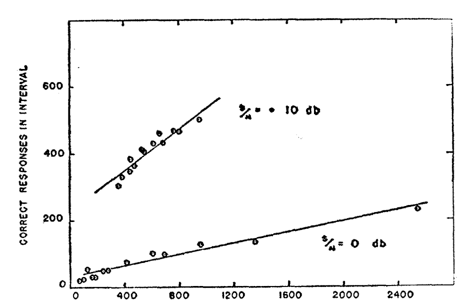

Fig. 2. Number of correct responses in an interval as a function of the number of responses in the interval [$p_c(s,r)$ versus $p(r)$]. In general, the greater the number of responses in an interval, the greater the median word-frequency of the interval. The points, one for each interval, represent the sum of the data for the six observers in the group.

about an hour a day for several days. A total of 1300 different monosyllabic content words were presented to each observer—100 words from each of 13 intervals. Within each experimental session, words were presented in a random order with respect to word-frequency, except that each interval had to be represented 12 times in each block of 156 trials. The observers were instructed to respond with a monosyllabic word.

The intervals were set up according to data obtained from the Lorge Magazine Count (*4*). There are approximately 6500 monosyllabic content words in this count; therefore, each interval permitted approximately 500 different response words. The median word-frequency of the intervals ranged from 1 to 736 (in the Lorge sample of 4.5 million word occurrences). The stimulus words were selected randomly except for the attempt to control word length.

Figure 1 shows the results in terms of Eq. 1. (The axes, however, are in terms of number rather than probability.) Figure 1 indicates that $p_c(s,r)$ is a constant proportion (k) of $p(s,r)$, or that the probability of correct response is independent of the interval of the stimulus word when the stimulus and response words agree in interval. For 0 and +10 db, k is approximately 0.63 and 0.94, respectively. Linear curves with zero intercept are drawn to indicate the excellent agreement between Eq. 1 and the data.

Figure 2 shows the results in terms of Eq. 4 (in terms of number). Figure 2 indicates that $p_c(s,r)$ is a linear function of $p(r)$, as predicted from Eq. 4. Since $p(s,r)$ differs from $p_c(s,r)$ only by the multiplicative constant k, Fig. 2 also indicates that $p(s,r)$ is a linear function of $p(r)$. Thus, the effect of response bias—the tendency for $p(r)$ to increase with the median word-frequency of the interval—is to increase $p(s,r)$.

Figures 1 and 2 support the response bias explanation by implying that response bias is a necessary condition for the word-frequency effect. When $p(r)$ increases with the median word-frequency of the interval—and this is what we mean by response bias—$p(s,r)$ also increases, and since $p_c(s,r)$ is proportional to $p(s,r)$, the word-frequency effect is obtained. The result of controlling response bias is to eliminate the word-frequency effect, as can be seen from the fact that $p_c(s,r)/p(s,r)$ is a constant (Fig. 1). Thus words of high word-frequency are not identified more accurately than words of low word-frequency when response bias is controlled.

Even though response bias accounts fully for the word-frequency effect, the magnitude of the obtained effect is greater than our mathematical interpretation of response bias explanation (Eqs. 1 and 2) can account for. The slopes obtained in Fig. 2 are considerably greater than the predicted slopes (k/n). Values of 0.31 and 0.08 were obtained for +10 and 0 db, respectively, while 0.07 and 0.05 were predicted. This means that an increase in $p(r)$ results in too great an increase in $p(s,r)$ and, therefore, too great an increase in $p_c(s,r)$. If Eqs. 1 and 2 are accepted as the appropriate interpretation of acoustical equivalence, the implication seems to be that, contrary to the contention of response bias explanation, words do carry some acoustical information about their interval (*5*).

CHARLES R. BROWN
HERBERT RUBENSTEIN
Air Force Command and Control Development Division, L. G. Hanscom Field, Bedford, Massachusetts

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Relation between the Inorganic Chemistry and Biochemistry of Bone Mineralization

Abstract. In vitro experiments with saliva resulted in precipitation of a mineral substance (dahllite or carbonate hydroxyapatite) which is comparable in composition and crystal structure to oral calculus. Similar mineral substances were produced from synthetic solutions containing sodium phosphate and calcium chloride (in addition to a buffer) in the presence of carbonic anhydrase and available carbon dioxide. It is concluded that the carbonate ion is essential to precipitation of bone mineral and that the principal biochemical catalyst in vivo is carbonic anhydrase. Bacteria are not essential to the precipitation, but they probably play a secondary role in connection with the formation of oral calculus, urinary calculus, and so forth.

On the basis of an understanding of the inorganic composition and crystal chemistry of the tooth and bone mineral (*1*), it was predicted (i) that the carbonate (or bicarbonate) ion is essential to the precipitation of the bone mineral, (ii) that the presence of a bacterial flora is not essential, and (iii) that some single biochemical substance, such as an enzyme, might catalyze the reaction and thereby govern whether or not mineralization takes place. The enzyme which immediately attracts attention is carbonic anhydrase.

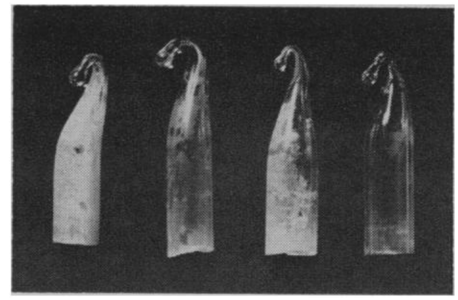

Fig. 1. Plummets immersed intermittently in (left to right): untreated whole saliva, saliva inactivated by heating, saliva to which carbonic anhydrase was added after heating, and saliva to which carbonic anhydrase and sulfanilamide were added after heating.

Inasmuch as the mineral substance of the commonest type of oral calculus is dahllite (a carbonate hydroxyapatite)—and therefore essentially similar to bone and tooth mineral—it was decided to investigate in vitro those processes which are related to the formation of oral calculus.

Our first experiment consisted of repeatedly dipping small glass plummets into saliva by means of a motor-driven apparatus. The saliva was collected from persons who readily accumulated calculus. After 5 days an appreciable deposit appeared on the glass plummet which was intermittently immersed in untreated saliva (see Fig. 1). After the saliva had been boiled, the amount of solid deposited on the plummet was insignificant. However, if crystalline carbonic anhydrase was added to the saliva for which the enzyme had been inactivated by heating, again a heavy precipitate formed on the glass plummet. If, in addition to the enzyme, sulfanilamide was added to inhibit the activity of the enzyme (*2*), virtually no deposit was formed. During the course of these experiments the only source of carbon dioxide, other than what was initially present in the saliva and was not removed by heating, was laboratory air.

Two additional sets of experiments were particularly informative. Both of these were done with solutions containing sodium phosphate and calcium chloride. Although the solutions were not sterilized, no significant bacterial contamination could have occurred. First it was discovered that when the solutions were saturated with carbon