seas (8) (that is, surface water freezes, adds salt to the water immediately below, which becomes more dense and sinks). In this case the amount of water is small and affects only the bottom 100 m. This sinking water mixes with the normal Atlantic-derived water but, being surface water, has a much higher tritium content. If the sample (0.9 ± 0.1 TU) were largely arctic surface water it could not have flowed down earlier than 1953 and still retain a tritium content of 0.9 TU. A similar age limitation would apply to the sample if it were Atlantic-derived, requiring improbably rapid subsurface flow rates in the arctic sea of about 10 cm/sec (if a path length of 3500 miles and 2 years' travel time are assumed). It is suggested that the water represented by this sample moved down along the continental shelf during 1953–55.

A sample of sea ice was also taken in the vicinity of the sea water samples. The loose snow cover was removed first, and only solid ice was taken. The high value of 4.0 ± 0.4 TU shows that precipitation as well as sea water forms part of the ice. Since surface snow melts in the summer, it is likely that some contamination occurs from seepage through the ice. This means that the dating of sea ice with tritium alone is, at best, a difficult problem.

A sample of ice from the Ward Hunt Island ice field (north of Ellesmere Island) collected in August 1954 had 2.2 ± 0.2 TU. Because of the results obtained from the sample of the sea ice, seepage and contamination are suspected here too. On the basis of a mean of 8 TU for precipitation (9, 10) in the prebomb era, it is estimated that the sample is at least 25 years old. If contamination had occurred in the summer of 1954 when precipitation probably had up to 100 TU, 2 percent of this would suffice to give the observed result on old ice containing negligible tritium. For 1953 precipitation (pre-Castle) to produce such an effect 25 percent replacement is required.

From the preceding it is seen that (i) tritium exists in measurable quantities in the ice and sea waters of the arctic; (ii) there is clear evidence of artificially produced tritium in the arctic surface sea water; (iii) the near-surface stratification of the polar sea water is confirmed; (iv) a new source of the deeper water of the Arctic Ocean was found to be in the Canadian archipelago; (v) downward seepage in arctic ice may make the dating of pack ice difficult; (vi) ice from the top of the Ward Hunt Island is at least 25 years old (11).

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References and Notes

1. A. P. Crary and R. D. Cotell, *Sci. Monthly* 75, 298 (1952).
2. B. J. Giletti, F. Bazan, J. L. Kulp, *Trans. Am. Geophys. Union* 39, 807 (1958).
3. H. von Buttlar and W. F. Libby, *J. Inorg. and Nuclear Chem.* 1, 75 (1955).
4. R. M. Brown and W. E. Grummitt, *Can. J. Chem.* 34, 216 (1956).
5. L. V. Worthington, *Woods Hole Oceanog. Inst. Tech. Rept. 53–92* (1953); private communication.
6. ——, *Trans. Am. Geophys. Union* 34, 543 (1953).
7. H. U. Sverdrup, M. W. Johnson, R. H. Fleming, *The Oceans* (Prentice-Hall, New York, 1942).
8. E. C. Lafond and D. W. Pritchard, *J. Marine Research (Sears Foundation)* 11, 69 (1952).
9. B. J Giletti, thesis, Columbia Univ. (1957).
10. S. Kaufman and W. F. Libby, *Phys. Rev.* 93, 1337 (1954).
11. Lamont Geological Observatory contribution No. 340. This research was supported in part by the Air Force Cambridge Research Center. The analytical techniques are described elsewhere (9). We wish to thank A. P. Crary and N. Goldstein for collecting the samples.
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Comparison of the Effects of Delayed Auditory Feedback on Speech and Key Tapping

Abstract. Delaying the return of a speaker's vocal output to his ears (the auditory feedback) radically changes his speech (1). The present report concerns the effect of delayed auditory feedback on simple key-tapping tasks. Evidence is presented which indicates that changes in speech and key tapping under delayed auditory feedback are analogous.

When a delay is instituted in the return of a speaker's vocal output to his ears (1), his speech changes in characteristic ways (2). The most common changes which occur are an increase in mean vocal intensity, an increase in phonation time, and a tendency to repeat sounds. There is considerable individual variation in the degree to which subjects manifest these changes while speaking under delayed auditory feedback conditions; however, almost all subjects show one or more of the above changes to some degree.

Preliminary studies on the effects of delayed auditory feedback on nonvocal motor tasks (3) have indicated that whistling and playing musical instruments are strongly influenced by delayed auditory feedback. Simple hand-clapping behavior is also reported to change under such conditions. A subject was asked to clap his hands six times as regularly as possible each time a click from a metrotome was presented through his earphones. When a delay of 250 msec was introduced in the return of the sounds of his clapping to a subject's earphones, he often clapped seven times instead of six and slowed down his performance.

It is not clear from the above data how closely the quantitative changes in nonvocal motor performances under delayed auditory feedback approximate the characteristic changes in speech under such conditions. Clarification of this issue is the rationale for our investigation (4).

Each of 14 young adult subjects was asked to repeat the speech sound "b" as in *book* in groups of three. During the first trial the subject's vocal output was amplified and returned without delay to his earphones. In the second trial a delay of 244 msec was introduced before the amplified speech was returned. Vocal performance was recorded on magnetic tape and later displayed on an oscilloscope and photographed. The resulting oscillograms give a graphic display of the subject's speech with respect to time and amplitude. Analysis of the oscillograms (Fig. 1, *A*) revealed that under delayed auditory feedback, subjects tended to speak louder (12 subjects), prolong sounds (eight subjects), increase pauses between sounds (11 subjects), and repeat the sound four times instead of three (eight subjects). Thirteen of the 14 subjects showed at least one of these changes.

Each of the subjects was then asked to tap on a key, the taps to be in groups of three. Each time a subject tapped the key, the lever hit a strip of spring steel with a strain gage mounted on it. During the first trial the sound produced was amplified and returned without delay to a subject's earphones (5). In the second trial a delay of 244 msec was introduced before the amplified sound was returned to his earphones. The amplification of auditory feedback for all conditions of the speech and key-tapping experiments was identical.

Each time a subject tapped the key, the output of the strain gage was amplified and fed into a direct-writing galvanometer to give a continuous record of the time and pressure characteristics of the subject's key tapping. Examination of the graphic records (Fig. 1, *B*) revealed that, under delayed auditory feedback, subjects tended to tap the key harder (12 subjects), hold down the key longer (five subjects), increase the pauses between taps (13 subjects), and tap four times instead of three (two subjects). All subjects showed at least one of the above changes (6). Thus, the changes that are observed in vocal performance under delayed auditory feedback are also observed in nonvocal performance under such conditions.

The change in speech and key-tapping performance following alteration in auditory feedback suggests that these two motor systems require auditory feedback for their control. However, the specific way in which the auditory feedback was altered—the delay in time—may be of even greater importance in explaining

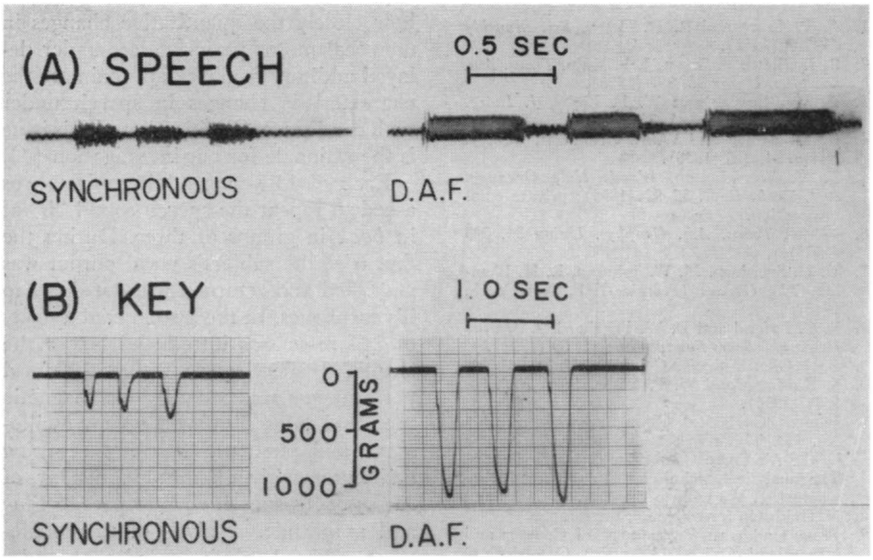

Fig. 1. (A) Oscillograms of a group of three articulations of the speech sound "b." The height of each sound display is proportional to vocal intensity. Under delayed auditory feedback, increases occur in vocal intensity, in phonation time, and in the time between sounds. Errors in number are not shown. (B) Display of amplitude and time characteristics of a group of three taps on a key. The downward displacement from the base line is proportional to the pressure exerted on the key by the subject. Under delayed auditory feedback, increases occur in pressure, in the time the key is held down, and in the time between taps. Errors in number are not shown.

the observed changes in motor performance than the fact that auditory feedback per se was interfered with. The fact that such marked changes followed a delay in auditory feedback indicates that there are critical time periods within which the sensory feedback accompaniments of a motor operation must be received to insure optimal motor control. Exceeding such critical time periods for auditory feedback is probably more disorganizing with respect to the motor operations studied than removal of auditory feedback altogether. More generally, it is possible that similar temporal alterations in sensory feedback may have similar effects on widely divergent motor functions. The parallel nature of the changes in speech and key tapping following the same delay in auditory feedback is consonant with this idea.

Performance under delayed auditory feedback probably also reflects mechanisms operating to restore control of a disordered motor function. Types of sensory feedback other than auditory—for example, tactile and proprioceptive—function in both speech and key tapping. It is possible that the increased amplitude characteristics of speech and key tapping under delayed auditory feedback operate to increase the amount of sensory feedback returning along undisturbed channels. The similarity of the changes in speech and key tapping with delayed auditory feedback may indicate that similar mechanisms operate to restore control in widely divergent motor systems.

The fact that key-tapping behavior can be so radically altered by delaying the auditory feedback of clicks raises the question of the usefulness of this technique in clinical audiometry. Presumably, the patient with psychogenic deafness, or the malingerer, would show the described changes in key tapping if he heard the delayed clicks. We are also exploring this application of our findings.

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References and Notes

1. Delayed auditory feedback is obtained through some simple modifications of standard tape recorders. See G. Fairbanks and R. Jaeger, *J. Speech and Hearing Disorders* 16, 162 (1951).
2. G. Fairbanks, *ibid.* 20, 333 (1955).
3. H. Kalmus, P. Denes, D. B. Fry, *Nature* 175, 1078 (1955).
4. This work was supported by a U.S. Public Health Service grant (B-1686) from the National Institute of Neurological Diseases and Blindness.
5. A lack of linearity in the relationship between the pressure of a tap and the intensity of sound produced makes the parallel with the speech experiment incomplete. In the speech experiment the intensity of the auditory feedback is directly proportional to the intensity of speech.
6. It should be noted that under delayed auditory feedback an occasional subject measurably *decreased* the time he held down the key and measurably *decreased* the time between taps. Similar observations were made for speech.

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Great Basin Petroglyphs and Prehistoric Game Trails

Abstract. Aboriginal petroglyphs ("rock-writing") in western and central Nevada have, up to now, remained a puzzle to archeologists as regards their function and location. Recent field investigation strongly suggests that these are connected with hunting magic, presumably aimed at success in the chase, and that they are located along routes of deer migration.

In the summer of 1958, assisted by Albert B. Elsasser and Eugene R. Prince, we carried out archeological reconnaissance in northern and central Nevada (*1*). Among the types of sites studied were those at which the primary evidence of activity of man takes the form of geometric and naturalistic designs pecked into boulder and cliff surfaces. These designs, called petroglyphs (*2*), occur in greatest quantity in North America west of the Rockies. (*3*).

Despite the numerous sites known, and studies made of western North American petroglyphs (*4, 5*), there is no evidence thus far presented which satisfactorily accounts for the occurrence of petroglyphs at certain locations. Cain's conclusion (*4*, p. 54) that "all such aboriginal carvings . . . were simply a medium for expressing some emotion over a spiritual or concrete event" is typical in its vagueness and points up the failure of students of the subject thus far to arrive at specific functional conclusions.

Our recent field observations show that in western and central Nevada nearly all petroglyphs occur along deer migration trails, at spots where the animals could be shot with bow and arrow. The petroglyph designs are therefore to be understood as evidence of the practice of compulsive magic by hunters, aimed at insuring success in the chase (*6*). From several deer hunters and state and federal wildlife service field men who have studied local deer migrations, we learned in detail of a number of routes which deer follow. In the late fall, when snow starts to fall, the deer follow these routes out of the high mountains into lower country, where they winter. The deer return by these routes to higher elevations as the snow melts.

At certain points, especially at the mouths or along the courses of washes or canyons through which the deer travel, are locations which are ideal for hunting from ambush. Thus, where a wash has cut through a rock reef and the canyon narrows to form a chute or gate, or where a canyon is narrow with a boulder-strewn bench perched above the defile, or in a saddle or pass, the moving animals (particularly if driven from the rear) could be forced to run past concealed archers. Preferred hunters' positions appear to have been at those spots where the ani-