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DELAYED AUDITORY FEEDBACK

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When S hears his own voice with a small time delay his speech may be seriously affected. The effects produced by delayed auditory feedback (DAF) include prolongation of vowels, repetition of consonants, increased intensity of utterance, and other articulatory changes. The significance of individual differences in susceptibility to DAF is considered in relation to personality and physiological characteristics. The technique may prove useful in the detection of auditory malingering and has possible implications for the understanding of stammering. The discussion relates the findings to models of speech control. Methodological problems and future research needs are outlined.

It has long been debated whether the successful regulation of skilled response patterns is dependent upon the continuous monitoring of the ongoing processes by means of feedback mechanisms. In the case of speech, it would seem to be necessary for the subject (*S*) to be repeatedly informed of the extent to which the skilled response pattern is proceeding smoothly so that appropriate corrections can be inserted into the sequence, where necessary. The appropriate information in the case of speech is derived from at least three sources: kinesthetic and proprioceptive feedback from changes in the muscular and sensory apparatuses involved in speaking and listening; auditory feedback transmitted via the bony structures of the organism, particularly the bones of the head; and auditory feedback transmitted through the air to the speaker's own auditory reception apparatus. In normal speech these three sources of information supplement each other and are presumably integrated at higher neural levels in the cortex.

It has also long been known (Cherry & Sayers, 1956) that interference with the natural relationships between ongoing speech and the consequent feedback of information could lead to severe disturbances in the smooth progress of speech, but it was not until the observations of Lee (1950a, 1950b, 1951) were published in America that interest in the detailed examination of the phenomenon quickened. Essentially, a situation is arranged such that *S* hears his own voice through headphones with a delay of about one-fifth of a second, usually while reading aloud a continuous prose passage. Under such conditions, many *S*s show a remarkable deterioration of speech fluency, together with other phenomena which will be described. The phenomenon has been variously called delayed auditory feedback, delayed speech

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feedback, and delayed sidetone. The term "delayed auditory feedback" (DAF) will be used in this review, since the effects of delay are not confined to speech, while the term sidetone has special meaning in engineering.

Since this review is concerned mainly with the production of abnormal patterns of speech by means of delayed feedback, it should be pointed out that alterations of feedback may often either facilitate rate of speech, or lead to *increased* articulation clarity; in fact it has been suggested that these techniques may be used to improve speech. Thus, intelligibility of speech has been demonstrated to increase when *S* speaks in noisy conditions (Butler & Galloway, 1957); when the high frequency components of airborne feedback are attenuated (Peters, 1955); and when airborne feedback is binaurally occluded (Black & Tolhurst, 1956). Black (1950) showed that level and duration of speech are dependent upon room size and shape. The speaker, in other words, adjusts both the level and precision of his speech under changed acoustic conditions to produce the most efficient communication possible. It would seem, furthermore, that the feedback mechanism sets limits to the rate at which normal speech can proceed, since it has been shown that artificially increasing the rate of airborne feedback enables *S* to speak more rapidly (Davidson, 1959; Peters, 1954).

Production of DAF

The delay of airborne feedback may be produced by the use of a magnetic tape recorder, modified so that it contains a fixed playback and a movable record head, or vice versa. The *S*'s voice production is recorded at the record head, delayed by an interval dependent on the distance between record and playback heads (at a constant tape speed) and then transmitted via the playback head to *S*'s headphones so that it is heard with the desired delay. A continuous loop of tape enables the high tape speeds necessary to be achieved, while an erase head ensures that the tape is clear when it again reaches the record head. In this way, Fairbanks and Jaeger (1951) were able to obtain delays up to .90 sec. at the relatively slow tape speed of 15 inches per sec. Tiffany, Hanley, and Sutherland (1954) obtained delays from .14 to 1.40 sec. It will be clear that varying delays can be obtained either by varying the distance between record and playback heads, or varying the tape speed, or both. As Tiffany et al. (1954) point out, a satisfactory piece of apparatus should allow for a wide range of delay times and continuously variable delay. Detailed descriptions of the apparatus required may be found in the two papers just mentioned.

Various other refinements may be added to the basic apparatus described above, both on the stimulus and response side. Thus, it may be desirable to control the intensity of feedback at *S*'s ear. This may be achieved most simply by an automatic volume control, interpolated between the playback head and the speaker's headphones.

The average auditory feedback delay under normal conditions is considered to be about .001 sec. and it has already been noted that it is possible to *shorten*, as well as lengthen, this delay. Peters (1954), by means of elaborate electronic tubes, obtained shortened delay times of .0003 and .00015 sec.; but a delay of .0005 sec. was achieved by Davidson (1959) simply by placing the microphone at the right corner of the speaker's mouth. A slightly longer than normal delay (.0015 sec.) was obtained if the microphone were placed 12 inches from and directly in front of the speaker's mouth. While Davidson's technique is probably not as reliable as that of Peters, and permits only small variations from normal delay times, it produced results very similar to those of Peters.

Materials

The task set *S* under DAF has varied widely. At one extreme, Chase, Harvey, Standfast, Rapin, and Sutton (1959) investigated the effect of DAF on the repetition of the sound [b] as in "book." Black (1951) utilized sets of five-syllable phrases carefully matched for characteristics such as equivalence of natural intensity induced by reading them in normal conditions. Prose passages have been most commonly used, varying from relatively uncontrolled material of varying lengths (Fairbanks, 1955; Spilka, 1954b; Tiffany & Hanley, 1952) to passages which have been phonetically balanced (Spilka,1954a), equated for difficulty level (Winchester, Gibbons, & Krebs, 1959), or chosen so as to contain all English speech sounds (Arens & Popplestone, 1959). At the other extreme, even the content has been indeterminate, as when *S* is asked to say nursery rhymes (Beaumont & Foss, 1957), or first say, and then explain the meaning of, simple proverbs (Korowbow, 1955).

Butler and Galloway (1957, 1959) used five two-digit numbers which were successively flashed at random in one of five different positions on a screen at varying rates of presentation. The advantage of this technique lies in the fact that it solves the problem of controlling the structure, content, and different "natural" intensity levels of words and phrases; eliminates variance in speaking rate within a test passage; and avoids the possibility of *S* counteracting the effects of the delayed signal by concentrating on the content.

Independent Variables

The principal independent variables utilized have been the delay time and the intensity level of the feedback at the speaker's ear.

Delay Time

The study by Black (1951) is representative. He used delay intervals varying from zero to .30 sec. by .03-sec. intervals. Fairbanks (1955) used intervals of zero, .10, .20, .40, and .80 sec. In most cases, intensity level of feedback has been held constant at a given value while delay time has been varied, but Butler and Galloway (1957) used four delay times and four intensity levels in a factorial design, while Atkinson (1954) used 10 delay times and three intensity levels. It may be noted that different groups of *S*s may be used for each combination of delay and intensity, or *S* may be used as his own control, experiencing each combination successively.

As has already been pointed out, two studies have shortened the feedback delay (Davidson, 1959; Peters, 1954) while Butler and Galloway (1957) used "random" delay, i.e., playing back a recording of *S* reading under zero delay while he was reading a second passage.

Intensity of Feedback

Several different criteria have been used in specifying this variable and would appear to account in part for discrepant results. The intensity level may be defined in a purely physical way, without reference to *S*. Thus, Atkinson (1954) presented the feedback at 0, 10, and 20 db. above a constant 75-db. noise level in the headphones. Peters (1954) presented the feedback 0 and 5 db. below and 5 and 10 db. above normal sidetone pressure level. More commonly, however, the intensity has been related to either the threshold for speech *reception* (SRT) (Hanley & Tiffany, 1954b; Tiffany & Hanley, 1952) or the threshold for speech *detection* (SDT) (Butler & Galloway, 1957). Since the former threshold is certain to be higher than the latter, it follows that an intensity level 75 db. above SRT produces a higher physical level than one which is 75 db. above SDT. Tiffany and Hanley (1956) have also utilized the spondee recognition threshold as a baseline.

It has been usual to maintain delay time constant while varying intensity level. Intensity level at the headphones has varied from 10 to 75 db. above SRT and from 20 to 80 db. above SDT.

In addition to the two major independent variables, Winchester and Gibbons (1957) contrasted various modes of presentation of DAF. With constant delay and intensity level, they presented DAF binaurally; uniaurally but without masking of the other ear; uniaurally but with the other ear masked; and without feedback or masking. In the latter case *S* wore headphones but received no feedback through them.

The only other modification of consequence is that utilized by Hanley, Tiffany, and Brungard (1958) who presented DAF in bursts rather than continuously.

Dependent Variables

In this section we shall present the main findings related to changes in a number of dependent variables when the principal independent variables are manipulated. The modifying influence of related independent intervening variables will be presented later.

Duration of Phrase

This refers to the time taken to read a standard phrase (Black, 1951) or a passage of prose, or any of the materials described earlier. If length of passage is divided by time taken, then a measure of reading rate is obtained. Hanley and Tiffany (1954b) calculated a mean rate reduction score, this being the time to read the passage under normal conditions minus the time to read it under delay. Various other measures, such as syllable duration time (Spilka, 1954b), percentage phonation time (Fairbanks, 1955; Spilka, 1954b), or time to make each verbal response in a free-responding situation (Korowbow, 1955) may also be included here.

Duration of phrase as a function of delay. Black (1951) measured the time to read five-syllable phrases as a function of delay times ranging from .03 to .30 sec. with intensity at headphones constant. He found that duration increased as a function of delay up to .18 sec. then declined; that, whereas the general trend was linear, there was a discrete increment at .06 sec. and that even the smallest delay produced a measurable increase in duration. Atkinson (1953) confirmed Black's findings while Fairbanks (1955), using a single sentence, found that total sentence duration and mean duration of phonations (uninterrupted periods of phonation) showed growth and decline characteristics similar to those of Black with a peak at .18 sec.

Discordant results were, however, obtained in a carefully controlled study by Spilka (1954b). He found that syllable duration and percentage phonation time both lengthened under DAF compared with no delay, but he could find no differential effect of delay upon those variables. Spilka's study did differ in important respects from that of Black, however. Different *S*s were used for the different delay conditions, relatively long prose passages were read, and the intensity level at the headphones was 120 db. for the feedback condition.

Conversely, both Peters (1954) and Davidson (1959) have demonstrated that speeding up the feedback rate by methods indicated earlier in this paper leads to a *decrease* in mean duration, that is, facilitates rapid speech.

Duration of phrase as a function of intensity. Two studies (Hanley & Tiffany, 1954b; Tiffany & Hanley, 1952) have assessed the effect on reading rate of various levels of intensity of feedback. The results of both studies indicated that a reduction in reading rate accompanied an increase in intensity of feedback, the relationship being roughly linear.

Interaction effects. Butler and Galloway (1957) used a factorial design involving four delay times and four intensity levels, different *S*s being assigned to each condition. They found a significant interaction effect between delay and intensity: at 50 db. intensity, delay times showed no differential effects, all being equally effectively different from synchronous feedback; whereas at 80 db. intensity, a differential delay effect was present with .17 sec. producing most errors. These results are in agreement with those of Black (1951) who used a high intensity level and with those of Tiffany and Hanley (1952), if allowance is made for the latter's use of SRT from which to measure intensity. The results of Butler and Galloway (1957) also suggest an explanation for Spilka's failure to find differential delay effects. Possibly, there is an optimal range of intensities, within which various delays will be differentially effective; outside these limits (on the high *or* low side) differential delay effects may be swamped by direct intensity effects at all delays.

Intensity of Utterance

DAF produces changes in the intensity of utterance, or sound pressure level of speech, as it is alternatively called. Black (1951) found that mean intensity of response increased as a function of increased delay up to .09 sec. delay, and then remained constant, and that even the smallest delay produced a measurable increase in intensity. Once again, his results were confirmed by Atkinson (1953) and once again Spilka (1954b) found that, although both mean vocal intensity and variance of vocal intensity increased under DAF, the pattern of change was not in agreement with the results of Black. Fairbanks (1955) found a constant increase of 10–12 db. over the entire range of delay times studied, but these findings of Spilka and Fairbanks do not necessarily conflict with those of Black, since the shortest delay time used by Fairbanks was .10 sec., while the shortest used by Spilka was .094 sec.

Fundamental Frequency

Fairbanks (1955) found a rise in fundamental frequency from 109.5 cps at zero delay to about 130 cps at all delay levels from .10 to .80 sec. No differential delay effect was apparent but he did not investigate delays shorter than .10 sec.

Intelligibility

The speech of *S* under DAF may be presented under noisy conditions to listeners who are required to make ratings of intelligibility of the speech. Atkinson (1954) found a decrease in intelligibility as intensity of DAF was increased, nonsystematic changes as delay was varied, but no interaction between delay and intensity. Davidson (1959) found that panels of judges could not detect any change in intelligibility of speech under slightly longer (.0015 sec.) or shorter (.0005 sec.) delays.

Articulatory Changes

The changes in speech rate and intensity previously described may be regarded as deriving from more basic articulatory changes, or both these changes may be regarded as deriving equally from some even more basic factor. The types of articulatory change which have been noted under DAF include the following: repetition of syllables and continuant sounds (Atkinson, 1953; Fairbanks & Guttman, 1958; Lee, 1951; Tiffany & Hanley, 1956), mispronunciations (Atkinson, 1953), omissions (Tiffany & Hanley, 1956; Fairbanks & Guttman, 1958), substitutions (Fairbanks & Guttman, 1958), number of word endings omitted (Korowbow, 1955), percentage of correct words (Fairbanks & Guttman, 1958). Clearly, some of these measures overlap in meaning. Tiffany and Hanley (1956) derived a measure of general speech effectiveness and Fairbanks andGuttman (1958) a measure of general articulatory accuracy. Deserving of special mention are the discovery by Korowbow (1955) that intrusions *diminished* under DAF, and the finding of Fairbanks and Guttman (1958) of an interaction between delay and type of error. Number of omissions doubled as delay changed from zero to .2 sec., but additions became 20 times as common. The sole discordant finding is that of McCroskey (1956). He found no change in four measures of mean number of correctly articulated words from no delay to .18 sec. delay. In view of Atkinson's (1954) failure to find any interaction between delay and intensity for intelligibility ratings, it is unlikely that the discrepancy between the results of McCroskey and those of Fairbanks and Guttman can be explained along these lines.

Measurement of Speech Changes

It will be clear from what has been said already that a variety of techniques has been used to evaluate the changes in speech which take place under DAF. In general, it may be said that it is not difficult to demonstrate changes under DAF, whether crude or refined indices of change are used. However, the stage has undoubtedly now been reached where more refined analyses of the kind described by Fairbanks and Guttman (1958) should be employed. A few comments only will be made. Hanley and Tiffany (1954b) paired records of normal adults reading under no delay with records read either under delay or no delay and requested judges to indicate the instances in which a pair included a delay record. Judges made few errors at high intensity feedback levels, but misidentified many normal records as DAF records. In another experiment, Hanley et al. (1958) provided judges with galvanic skin records only and required them to determine whether DAF had been applied and, if so, at what intensity level. This task surprisingly was very successfully accomplished.

Verzeano (1950, 1951) has described the use of a frequency analyzer which records "units" of speech in terms of an arbitrarily determined pause in the flow of speech, e.g., it records each time the flow of speech is interrupted for a period longer than one second. Although this technique has not been used to analyze speech under DAF, it could prove a very useful method of analysis.

Sherman and her colleagues have investigated very thoroughly various scaling methods for estimating the difficulty of speech at a given moment, and have concluded that the method of equal-appearing intervals is the most appropriate (Lewis & Sherman, 1951; Sherman, 1952; Sherman & McDermott, 1958; Sherman & Moodie, 1957). Rawnsley and Harris (1954) used the spectrogram (a machine which produces a visual record of the frequency, intensity, and duration of any sound) to compare the structure of words and phrases spoken under DAF and normal conditions by the same *S*. They found that, if part of a word is repeated, the first utterance of the part resembles the structure of the part when spoken in isolation, whereas the repetition shows a change towards the structure of the part in relation to the whole. This method of analysis has so far been used only on rare occasions to analyze speech changes under DAF.

On the whole, it may be said that a multiplicity of techniques is available for accurate analysis of response measures. Thus far, the most detailed studies of the exact nature of the changes in speech under DAF are those of Fairbanks (1955) and Fairbanks and Guttman (1958).

Adaptation to DAF

Adaptation effects have been studied from two aspects: the extent to which adaptation takes place while reading continues under DAF, and the degree to which speech returns to normal when delay is removed.

Adaptation to DAF

Atkinson (1953) found no adaptation of either sound pressure level or duration when *S* read a total of 60 standardized phrases. Winchester et al. (1959), however, used 10 200-syllable passages equated for difficulty and read under a delay of .16 sec. at 60 db. No adaptation was found during the first two passages (400 syllables); but adaptation did take place during the remaining reading, the tenth passage being read about 12 sec. faster than the first (the problem of control for practice effects is discussed later). Tiffany and Hanley (1956) required *S* to read a 45-word prose passage 12 times on two occasions separated by a week. Speed of reading showed no adaptation within or between sessions; fluency breaks (omissions and repetitions) showed no change *within* a series of readings, but declined significantly *between* series. The correlation between reading speed and fluency was .72 for the first series, but only .39 for the second series. Tiffany and Hanley concluded that readers may learn to avoid the "stuttering" but do not overcome the change in rate, that is, adaptation is only partially achieved. Beaumont and Foss (1957) found a correlation of .83 between reading times for equivalent passages under DAF read at an interval of 2 weeks.

On the whole, then, the results of these studies indicate that while some degree of adaptation does take place to continued DAF, the adaptation is not complete. Winchester et al. (1959) have indicated that these adaptation effects may be prevented by increasing the feedback intensity or by changing the delay time, while Hanley et al. (1958) prevented adaptation by presenting DAF intermittently.

Persistence of DAF Effects on Normal Speech

The results here are fairly consistent. Tiffany and Hanley (1952) found no difference for two control readings, one taken before and one after under DAF. Black (1955), using a similar design, found that duration effects tended to persist into normal speech, but not changes in sound pressure level. Leith and Pronko (1957) found an immediate return to normal speech rate and level when DAF was removed and suggest that a possible source of variance here is whether, during the control readings, *S* knows whether or not DAF will again be applied. Finally, Tiffany and Hanley (1956), in the study previously referred to, reported no difference in mean reading time for 12 pre- and 12 post-DAF normal trials. They did show, however, that a residual effect was present in *S*s whose speech had been severely affected by DAF, whereas *S*s relatively unaffected by DAF showed an *increase* in normal reading rate. In general, however, it is clear that most *S*s are able to resume normal speech as soon as DAF is removed.

Confounding Variables

Although the standard of research work in the field of DAF has been of a relatively high standard, and although the phenomenon naturally lends itself to satisfactorily designed experiments, a surprisingly large number of traps await the investigator. The control problems which arise may be grouped into a number of categories.

Reading Material

We have already outlined the main types of material which have been used. Black (1951) has constructed five-syllable phrases equivalent in mean duration and intensity values under normal conditions, while Arens and Poppleston (1959) used a passage containing all English speech sounds. It will be obvious that if equivalent passages are to be used under various delay conditions then both their content and structure must be controlled, since different words and phrases have different "natural" intensity levels, as Black showed. Indeed, Kline, Guze, and Haggarty (1954), although using only a single case, suggested on the basis of their findings an interaction between difficulty of the material and the effect of delay—the more difficult passages showing a disproportionate degree of disturbance compared with the easy. Similarly, Spilka (1954b) found a significant interaction between length of reading passage and delay time for average syllable duration; and a significant main effect of passage length for vocal intensity and vocal intensity variance.

Progressive Errors

The use of a large number of delay times and intensity levels in a factorial design naturally involves the use of large numbers of *S*s, if the numbers in each cell are to be of the order of, say five. Many authors have preferred to subject each *S* to every condition, but it is clearly essential in this case to control for progressive errors by appropriate designs. This has not always been done (e.g., Korowbow, 1955).

Sound Pressure Level at the Ear

It has already been pointed out that different methods have been used to estimate sound pressure level at the ear. It would seem to be highly desirable that some standard form of reference be adopted. Chaiklin (1959) has recently discussed and compared several different types of threshold measurement. A related problem concerns whether or not the sound pressure level should be maintained constant while *S* is speaking or whether it should be allowed to vary as *S* varies the intensity of his response. Atkinson (1952) showed that the loudness of the stimulus tone affects the sound pressure level of *S*'s response. The question is clearly an important one, since it has been shown that DAF produces an increase in intensity of *S*'s response which, of course, raises the level at the ear, a vicious circle being set up. Curiously, the effects of controlled versus uncontrolled sound pressure level at the ear have not been experimentally investigated. Butler and Galloway (1957) showed that loudness per se does not affect speed of reading, since no effect of loudness was found with synchronous feedback.

Pretraining

Little attention has been paid to the question of familiarizing *S* with the situation of facing complex apparatus, wearing closely-fitting headphones, and so on. Tiffany and Hanley (1952) gave *S* 5 minute's preacquaintance with the passage they were to experience subsequently under DAF. Atkinson (1953, 1954) and others have given training in reading Black's standardized phrases while Butler and Galloway (1957) trained *S* to become familiar with the location of the positions on the dial where the numbers would appear.

Reading Rate Instructions

Only one study has deliberately varied instructions concerning reading rate. Peters (1954) instructed *S* to read at natural and at maximal rate on spearate occasions. In both cases, an increase in the rate of feedback was accompanied by a faster reading rate. No studies concerned with increased delay in feedback have examined this variable, which could be of some importance, since changes in reading rate accompany changes in delay of feedback.

Consistency of Normal Reading Rate

In studies on adaptation to DAF, it would be important to have control data on practice effects. Gibbons, Winchester, and Krebs (1958), used 10 200-word passages of equal difficulty which were read successively without a break by *S*s wearing headphones. The rate of reading remained remarkably consistent throughout the 10 passages, no effect of prolongation of reading time being found.

Noisy Background

It has been shown by Butler and Galloway (1957) that the effects of DAF are not simply due to interference effects of a noisy background, since the condition of random delay produced no disturbance. Winchester and Gibbons (1958) investigated the effects of a masking tone, presented uniaurally to one group, binaurally to another, at 80 db. above sensation level on the time to read a 500-syllable prose passage under no delay. No difference in time was found between these groups and a group reading under no delay wearing headphones but without the masking tone. In a study by Peters (1956), speakers read standardized intelligibility lists while simultaneously hearing various kinds of auditory signals, ranging from the same, similar but not identical, and unrelated material to meaningful "flight-patter" phrases and babel. The results indicated speakers were more intelligible when the auditory signals were babel or words similar to those being read than when the signals were the same or unrelated words.

Loudness Recruitment

This phenomenon occurs in partially deaf people who may perceive stimuli above their hearing threshold as louder than do people with normal hearing. Thus, if partially deaf *S*s are included in a control group under DAF they may show more reaction to DAF at high intensity levels than normal *S*s because of loudness recruitment. The problem has been investigated. Harford and Jerger (1959) found that a group of normal *S*s reading under DAF at various intensity levels above a binaural masking tone (which artificially produced partial deafness) showed more disturbance than control *S*s reading without masking, presumably because of the effects of experimentally induced loudness recruitment.

Stimulation Deafness

It is well known that continued exposure to high intensity sound produces partial temporary deafness. The effect of this in the DAF situation would be to reduce the sound pressure level at the ear if *S* were reading a continuous prose passage. The effects of stimulation deafness in relation to DAF have not been investigated.

INDIVIDUAL DIFFERENCES

One of the most striking features of DAF has been the marked individual differences in the degree to which *S* can continue to speak normally under DAF. A few *S*s show little disturbance; others are almost totally incapacitated; the majority fall somewhere between these extremes. Most of the work in this area has been concerned with the study of personality traits and physiological concomitants under DAF.

Personality Traits

There seems to be general agreement that speakers with high verbal facility (Arens & Popplestone, 1959[2]) or high initial intelligibility (Atkinson, 1954) are less affected by DAF than speakers with low verbal facility or intelligibility. In line with this, Beaumont and Foss (1957) found that poor speakers showed greater adaptation during DAF, because the better speakers performed at a higher level throughout.

The difficulties of relating more specific personality traits to reaction to DAF were shown in an early study by Spilka, Hanley, and Steer (1953). In the first part of the study they measured speaking intelligibility under conditions of high noise interference (without delay) and found that *S*s most successful in overcoming interference were aggressive and intolerant, i.e., accustomed to overcoming obstructions by force. A replication of the study, however, failed to confirm these indications. In a later study, Spilka (1954a) correlated various indices of vocal disturbance to a number of personality traits measured by the California Test of Personality (Secondary Series), Guilford's STDCR, the total E Scale, and the Paranoia and Schizophrenia subtests of the MMPI. Spilka's general hypothesis was that *S*s who rely on exteroceptive (in this case, auditory) cues will be most affected by DAF, since this involves a disturbance in external balance, whereas *S*s who rely mostly on proprioceptive (kinesthetic) cues will be least affected. The underlying assumption is that all

[2] This study actually dealt with verbal knowledge rather than verbal fluency.

*S*s rely on a combination of internal and external cues for monitoring purposes, but to differing degrees. From this general hypothesis, he derived a number of specific predictions, e.g., that individuals with negative self-attitudes, and paranoid and rigid persons, will all be hypersensitive to external stimulation and hence will be very susceptible to DAF; whereas schizoid persons who depend largely on internal cues, will show low susceptibility to DAF. Spilka found that the voice variable most consistently related to personality variables was change in vocal intensity variance. Increases in this variable were related to strong negative self-attitudes, poor personality adjustment, and paranoid tendencies; whereas decreases were related to schizoid modes of behavior. The relationships were all low but consistent and do provide some support for the general hyplothesis. Further support comes from a study on schizophrenic and normal children by Goldfarb and Braunstein (1958). Their hypothesis that schizophrenic children pay less attention to external stimuli than do normal children and should therefore be less affected by DAF is almost identical with that of Spilka. They rated the behavior and speech of 16 schizophrenic and 25 normal children aged about 9 years. Under normal reading conditions, the speech and behavior of the schizophrenic children was significantly poorer than that of the normal children. Under DAF, however, all of the normal children showed gross speech impairment whereas the schizophrenc children showed very diverse results —from no breakdown in speech to severe disturbance.

Korowbow (1955) used an 852-item personality test, factorially designed, and obtained correlations between speech disturbance and personality traits which may be regarded as generally in line with those presented already; e.g., an increase in intensity of vocal amplitude was associated with "sensitivity" and "emotional reticence." Comparisons, however, are not easy in the absence of strictly comparable personality traits.

Beaumont and Foss (1957) found a positive relationship between tendency to perform poorly under DAF and tendency to show perseveration on the Luchins *Einstellung* test.

It can be seen that a promising beginning has been made in relating personality variables to individual differences in performance under DAF. Whether personality variables can be shown to play more than a minor role in the explanation of these differences remains to be seen.

Physiological Changes under DAF

Doehring (1956), and Doehring and Harbold (1957), showed that under DAF at high intensity level, there was a significant increase in forearm and head muscle action potentials and heart rate compared with performance under no delay and in the resting state. Galvanic skin resistance decreased (indicating increased physiological reactivity) under DAF, while respiration showed a significant decrement at the end of each reading. A suggestion in the earlier study that there was a negative correlation between amount of speech disturbance and amount of physiological disturbance was only partially confirmed in the later study, significant negative correlations being found between heart rate and speech rate and between heart rate and speech level. Hanley et al. (1958) found that at high intensity levels all *S*s tended to show GSR disturbance, but that at low levels there was great variability. Once again, interaction effects are shown to be of crucial importance. Hanley et al. also reported that some individuals manifesting severe GSR disturbance showed almost no breakdown in speech, thus supporting to some extent the suggestion of Doehring. Further study is indicated.

Developmental Aspects

Developmental studies of susceptibility to DAF may throw much light on the acquisition of speech monitoring habits, but so far little work has been reported. Goldfarb and Braunstein (1958) reported gross speech impairment in all normal children in their group, the average age being about 9 years. Chase, Sutton, First, and Zubin (1961) found that the speech of children aged 4–6 years was significantly less affected by DAF than was the speech of children aged 7–9 years. Again further work is clearly indicated.

DAF AND AUDITORY MALINGERING

A great deal of interest has been shown in the possibility of using DAF to detect psychogenic deafness. Tiffany and Hanley (1952) showed that normal *S*s were unable to overcome the effects of DAF when instructed to behave as if they were deaf. Hanley and Tiffany (1954a) described a case of psychogenic deafness in which the patient had an apparent bilateral loss for pure tones of 75–80 db. However, severe disruption of speech occurred under DAF at 50 db. intensity level. Further tests revealed normal hearing for speech.

Gibbons and Winchester (1957) investigated 70 *S*s with medically diagnosed uniaural organic hearing losses, the threshold differential being at least 40 db. between ears. In one test condition, DAF was presented to the better ear with the poorer ear masked; in the other condition, the reverse was the case, order being counterbalanced. It was found that oral reading time was significantly longer when the poorer ear was masked and the better ear subjected to DAF than vice versa; that is, when the better ear was masked, the poorer ear was relatively unaffected by DAF because of deafness in that ear. Gibbons and Winchester concluded that this technique can help to estimate the relative extent to which deafness is functionally or organically determined. Kline et al. (1954), using one *S*, showed that less speech disturbance was manifest under DAF when *S* was hypnotically deafened than in the waking state. Hanley et al. (1958) were also optimistic about the use of DAF to detect functional deafness, particularly in conjunction with changes in GSR thresholds. More recent work, while not denying the possible value of DAF for this purpose, has considerably qualified the earlier claims. Butler and Galloway (1959) point up the particular problem of the patient with mild organic hearing loss with a large functional overlay. The use of DAF is rendered difficult by the large individual differences in response to DAF by normal *S*s, and by the recruitment phenomenon in hard-of-hearing *S*s, already discussed, which might result in some hard-of-hearing patients behaving like normal *S*s at some feedback intensity levels. They compared 60 hard-of-hearing *S*s with 48 controls under DAF at 50 and 80 db. above SDT. Discrimination between the groups was obtained only at 50 db. and even at this intensity there was 30% misclassification. For individuals, the amount of hearing loss could not be accurately predicted. The pessimistic conclusions of Butler and Galloway are perhaps somewhat exaggerated, however, when it is realized that selection of the criterion groups would not be perfectly reliable.

Harford and Jerger (1959) tested a normal control group and groups of patients suffering from labyrinthine hydrops (a form of deafness accompanied by loudness recruitment) or bilateral otosclerosis (a form of conductive deafness without loudness recruitment). To control for differences between the two clinical groups in ability to understand speech a group of normal *S*s with binaural masking tone (producing recruitment but not speech discrimination loss) was added, while to control for age and deafness per se a fifth control group was added consisting of older normal *S*s tested with and without ear plugs. These five groups were tested on the apparatus devised by Butler and Galloway (1957) at a delay of .167 sec. and at intensity levels of 10–50 db. above a spondee threshold. The results indicated that recruitment does produce an exaggerated effect of DAF which cannot be accounted for by speech discrimination loss (the masked normal and hydrops groups were like each other and different from the first control group at all sensation levels). A completely unexpected result was the high error scores of the otosclerotic group, which differed significantly from the results for the fifth (normal) group. Some of the difficulties may be overcome by using a tapping test instead of speech. Not only does this overcome problems posed by bone conduction but Chase, Sutton, Fowler, Fay, and Rubin (1961) have shown that there is a significant effect of DAF on rhythmic tapping at feedback intensity levels as low as 10 db. above the threshold of hearing for a click containing frequencies from 500 to 2,000 cps.

Thus, the usefulness of DAF as a test for psychogenic deafness is at present not clear. It is certainly clear, however, that loudness recruitment makes interpretation of particular results very difficult.

DAF AS A STRESSFUL SITUATION

Mention may be made that DAF has been successfully used as a form of stress by Pronko and Leith (1956) and Forney and Hughes (1961).

DAF IN TASKS OTHER THAN SPEECH

The effects of DAF have been shown in a number of tasks not involving speech and, indeed, in tasks where it would superficially appear as if auditory feedback would play a relatively small role. Thus, Kalmus, Denes, and Fry (1955) found that rhythmical hand clapping (expected to be primarily mediated by proprioceptive feedback) was disturbed by DAF. Lee (1951) and Chase et al. (1959) discovered disturbances of tapping under DAF; e.g., the key was tapped harder, held down longer, more taps given than asked for, and pauses between taps lengthened. In a recent more extensive study Chase, Harvey, Standfast, Rapin, and Sutton (1961) compared the effects of DAF on similar speech and tapping tasks (repeating [b] and tapping in groups of three). They found that similar types of errors were committed in both types of task; but that the correlation between error scores for the two tasks was insignificant, indicating that the feedback monitoring systems are relatively independent. Hanley and Tiffany (1954a), and several others, have reported that no individual has even approximated normal whistling under DAF, this skill being particularly subject to disturbance.

It may be noted in passing that very similar disturbances have been found in nonauditory monitoring tasks. Thus, Van Bergeijk and David (1959) delayed visual feedback of handwriting while kinesthetic feedback remained unchanged. When delays of up to .50 sec. were introduced in the visual feedback, disturbances in handwriting were produced which matched those found in speech.

DAF AND STAMMERING

One of the most interesting features of research in this area has been the implications of the work for the understanding of stammering behavior. Lee (1951), in one of the earliest references, suggested that stammerers do not stammer when they are members of a group because feedback is provided by other group members. This focused attention on the possibility that stammering may be related to a defect in the perceptual monitoring of speech processes. If the monitoring of ongoing speech involves, as Lee (1951) suggested, a closed feedback loop, then any failure in the feedback will lead to the signal (a particular word unit in this case) being repeated until the appropriate information does reach the monitoring system (perhaps by summation of stimuli) and the speaker can proceed. In a series of brilliant hypotheses, experimentally tested by deduction at every point, Cherry and Sayers (1956) presented cogent evidence that stammering is associated with the perception of the low-frequency components of speech which are mainly bone conducted. Blocking of air-conducted feedback did not affect stammering. If, however, the stammerer were completely prevented from hearing his own voice while speaking by the use of very intense white noise, stammering was completely inhibited and normal speech resulted. Masking the high frequencies alone had no effect, whereas masking the low frequency components only had the same effect as white noise. These facts, of course, are in line with the common observations that stammerers often do not stammer when they sing or whisper. The exact nature of the perceptual disability is unknown but it is interesting to note that in stammerers the disability is apparently related to a dysfunction of bone-conducted feedback, whereas in normal *S*s stammering-like behavior is induced by interference with air-conducted feedback. Cherry and Sayers further confirmed the importance of perceptual monitor ing of speech by showing that the "shadowing" technique (in which the stammerer follows closely and aloud a passage which he does not see and which is read by someone else) not only leads to total suppression of the stammering, but is a valuable therapeutic technique. The results obtained by Cherry and Sayers have been independently confirmed by Shane (1955) and by Maraist and Hutton (1957). The latter found that a 90-db. masking white noise resulted in the stammerer's speech approximating normal reading speed and accuracy. Utilizing various intensities of masking, they also reported a special increment in efficiency at 50 db.

The Cherry-Sayers hypothesis was further examined by Sutton and Chase (1961), who found no difference in reading speed of stammerers under conditions involving the presentation of white noise continuously while *S* was reading; while he was speaking but not while he was silent;

or while he was silent but not while he was speaking. This experiment, however, cannot be regarded as a crucial test of the perceptual defect hypothesis, since the feedback from speech is heard with a slight delay and hence in both of the discontinuous white noise conditions, at least part of the feedback would be masked.

Whether or not the speech disturbances characteristic of stuttering are comparable to the disturbances found in normal *S*s under DAF has been investigated only by Neelly (1961). He found that the adaptation effect in stutterers repeatedly reading the same prose passage (i.e., the tendency for stuttering to diminish) was quite different in degree and structure from that found in normal *S*s reading under a delay of .14 sec. Further, listeners were able to distinguish speech samples from the two groups with a high degree of accuracy but could not distinguish the groups when both were speaking under DAF. Neelly (1961) concluded that the perceptual characteristics of stutterers' speech are quite different from those of normal *S*s under DAF and that "an adequate account of stuttering behavior—or the more comprehensive stuttering problem—is not to be found in the auditory feedback mechanism" (p. 78). Neelly's results must be viewed cautiously, however, since he used only one delay interval and his normal *S*s had presumably received much less practice in reading continuously under DAF than had the stutterers under normal conditions. He also found large individual differences in the reaction of stutterers to DAF.

A little known study by Birch and Lee (1955) showed that speech impairment could be significantly reduced in *S*s suffering from expressive aphasia by a masking tone of 265 cps presented binaurally. Their results were not, however, confirmed in a study by Weinstein (1959).

Discussion

As pointed out earlier, the monitoring of speech involves the utilization of feedback information from three sources: kinesthetic and proprioceptive feedback resulting from the movements involved in speaking, transmission of spoken sounds to the auditory apparatus via the bony structures, and transmission of sound via the air to the auditory apparatus.

It is clear that the disruption of speech which results from DAF is not related to the *absence* of any of these feedback mechanisms per se, though presumably if all forms of feedback were totally eliminated speech could not proceed. So long, however, as one or more of the feedback mechanisms is in working order, relatively normal speech will proceed even in the absence of the other two. Of the three modes of feedback control, it seems likely that the kinesthetic mode is the least important as far as the phenomenon under discussion is con-concerned. Only minor information is provided by this mechanism of the actual nature of the sounds which are being produced. Furthermore, McCroskey (1956) eliminated, by anesthetization, sensory innervation of the lower lip and cheek, the buccal and lingual gingivae, the anterior two-thirds of the tongue, the alveolus and teeth, and the upper lip. While he found a significant decline in accuracy of articulation under these conditions, the anesthetization did not affect the rate of progress of speech, although DAF did.

It might be supposed that in normal speech the three kinds of feedback are synchronous as to transmission time and that asynchrony under DAF is the critical factor. But the effects of DAF do not seem to be completely accountable for in terms of an artificially produced asynchrony of this kind. McCroskey (1956) pointed out that if asynchrony were the prime factor, then there should be a lessening of the effects of DAF if the kinesthetic feedback were eliminated or reduced by anesthetization. In fact, however, in his experiment, anesthetization did not lessen the DAF effect as far as rate of progress of speech was concerned. Again, the fact that the DAF effect increases as a direct function of the sound pressure level argues against an asynchrony explanation, since the increase should progressively mask the undelayed bone-conducted feedback. Several authors have pointed out that the high level of feedback is necessary to prevent *S* from counteracting the airborne auditory delay by utilizing bone-conducted or residual-nondelayed auditory feedback. In other words, *S* can resist the DAF effect to a considerable extent, provided he can still utilize the (now asynchronous) bone-conducted feedback.

There is some empirical evidence relating to this problem. Winchester and Gibbons (1957) found that monaural DAF without masking of the other ear produced less disturbance than monaural delay with masking of the other ear. However, Chase and Guilfoyle (1962) presented delayed and undelayed feedback simultaneously to both ears. The gain of the latter was either one-third, two-thirds, or equal to that of the DAF. They found that while increasing the gain of the undelayed feedback progressively reduced the disturbance produced by the DAF, speech did not return entirely to normal even when the gain of the undelayed was equal to that of the delayed feedback. Both these studies indicate that availability of accurate feedback information through one channel assists *S* in resisting the disrupting effect of DAF.

These observations indicate the necessity for postulating some central controlling mechanism and the most obvious one to postulate is the existence of a comparator within the closed cycle feedback system. In this connection, the observations of Fairbanks (1954) are of great interest. Fairbanks pointed out that, in monitoring speech, any postulated mechanism must be able, not merely to *estimate* the present state of the system, but also to *control* that state or, in other words, to *predict* the future course of events. In his model of a closed cycle control system for speaking, Fairbanks included an effector unit (producing the output from the system), a sensor unit (which picks up the output), and a controller unit. The latter comprises a storage unit, a comparator, and a mixer. The storage unit contains the short-term instructions for a set of speech units which must be displayed (through the effector unit) in a definite time sequence. As each sequence is completed, a new set of instructions appears in the storage unit. The signal in the input at any given moment is transmitted both to the effector unit and to the comparator and mixer. The feedback signals from the effector unit to the comparator are compared with the input information contained there and any discrepancy between the signals (the error signal) is relayed to the mixer unit. This latter unit combines the input signal and the error signal in such a way as, eventually, to reduce the difference to zero. At this point the system is in equilibrium. Within the comparator, however, is contained a predicting device which continuously predicts (presumably on the basis of past experience) the future point at which the error signal will be zero. Thus, the input may be changing even while the effector unit has not yet completed the transmission of the current unit. With a system of this kind, it is possible to predict what will happen if part of the system does not function properly. Thus, if, as happens in DAF, the transmission of information from the effector unit through the sensor is delayed, the comparator will transmit an error signal to the mixer and the signal may be repeated, or the whole system may halt until the effector signals are transmitted back. It has been suggested (Stromsta, 1959) that the locus of the comparator may be the cerebellum.

It has, of course, been disputed whether serial skills such as speech, tracking behavior, etc., can be continuously monitored in this way, when regard is had to the speed of neural conduction from the effectors to the brain. An alternative formulation would argue that the storage unit described by Fairbanks would trigger off a set of speech units which would then proceed without further monitoring unless some serious breakdown occurred. The effects of DAF would represent one such example of a breakdown. Chase, Rapin, Gilden, Sutton, and Guilfoyle (1961) pointed out that delayed auditory feedback is in a sense a misnomer, since the phenomenon does not really refer to a change in normal feedback, but to a delayed auditory *event* which is actually foreign to the normal state of affairs. In their study, they were able to show that if *S* were prevented from watching his tapping (decreased visual feedback) and at the same time an unrelated visual stimulus were presented just after a tap, disorganization of the tapping was produced. It may be noted in this connection that stammering can be completely inhibited if *S* and the experimenter read a passage of prose simultaneously, even though the experimenter is reading quite different material to *S*, or is reading gibberish. On the other hand, Gibbs (1954), who provided a careful evaluation of the literature relating to feedback control, concluded, on the basis of his experiments, that continuous monitoring does appear to be feasible, while Stromsta (1959) considers that neural transmission times are compatible with the hypothesis. The explanations are not, in fact, incompatible with each other, but the problem of how they interact remains to be solved.

The model put forward by Fairbanks works, of course, because it was constructed to parallel the observed facts. While this does not lessen its value, it does not reduce the necessity for considering other possible explanatory theories nor the necessity for careful further experimentation of the kind carried out by Chase (1958). He argued that if DAF facilitates the circulation and recirculation of speech units in the speech-auditory feedback loop, then it should be possible to repeat a single speech sound more often in unit time under delay than under normal conditions. In his experiment, one group repeated the sound [b] as quickly as possible for 5 sec. under synchronous (i.e., faster than normal) feedback; and then repeated the sound with a feedback delay of .216 sec. A control group was tested twice under synchronous delay. Seventy-five percent of the experimental group showed a faster rate of repetition under delay.

A great deal more experimentation is still needed to explore the relationships between the three types of feedback and their disruption. It might be expected, for instance, that similar disruptive effects on speech would be produced if bone-conducted feedback were delayed, with air-conducted feedback blotted out. In this connection, Siegenthaler and Brubaker (1957) have made many valuable suggestions as to future lines of research, many aspects of which have scarcely as yet been touched. Their suggestions fall into three categories. In relation to the speaker, they mention individual differences in relation to intelligence, reaction time, reading ability; amount or type of speech disturbance in relation to frustration tolerance, personality traits, hearing loss. In relation to speech output, they mention the effect of DAF on an acquired as opposed to a native language; the effect of DAF on reading passages of various consonant /vowel structure; and its effect on passages of differing levels of difficulty. Finally, in relation to modifications of the apparatus, they mention the use of separate microphones for each ear with DAF presented separately to each ear, but with different delay times. In this connection, it may be mentioned that, since 1950, at least 50 higher degree theses have been written on DAF, many of them dealing with important aspects not covered in the published literature. Yet only a small proportion of these theses has been published.

There can be no question but that the technique of DAF provides a most useful method of investigating the role of feedback mechanisms in the control of skilled response patterns and, as such, deserves, and requires, more attention than it has so far received, especially since it is clear that the technique is readily applicable to skills other than those involved in speech.

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