THE EFFECTS OF ELIMINATION OF SUBVOCALIZATION WITH ELECTROMYOGRAPHIC FEEDBACK

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We hereby recommend that the Dissertation prepared under our supervision by Herbert Arthur Christian Ninness entitled The Effects of Elimination of Subvocalization with Electromyographic Feedback

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Dedication

In gratitude for her constant encouragement
of the author,
and also in recognition of her role of
friend and advisor,
This dissertation is gratefully dedicated
to the memory of

Mary L. Deaton.

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The Effects of Elimination of Subvocalization with Electromyographic Feedback

Gibson (1975) defines subvocalization as,

> Speech whose range goes from audible sound (e.g. whispering), to the movements of speech musculature which must be highly amplified to be detected, to the extreme of speech so implicit that an investigator can make no physical observations. (p. 340)

Subvocalization is operationally defined here as the emission of laryngeal muscular activity which approximates articulation of the written word during silent reading. The behavioral process of subvocalization while reading goes by many different names in the literature. It will be referred to in this paper using the terms: subvocalization, subvocal speech, subvocal behavior, covert vocalization, silent speech, inner speech, and implicit speech. While some of these terms may have unique connotations within the confines of specific publications, it will be understood that for our purposes these classifications are synonymous.

The problem as to whether subvocal speech is a necessary part of efficient silent reading has probably been a subject of some controversy since the educational process began. It has a long history of theoretical interest

(Edfeldt, 1960). This is probably true because the subvocal act is often compared with the thinking process as controlled by external stimuli (Gibson, 1975). Beyond the theoretical analysis, the technological importance of subvocal speech has been debated by educators. The controversy has typically raged between those who believe subvocalization hinders the reading process by slowing down the rate of reading or by interfering with the thought process, or both, and those who believe subvocalization to be a natural facilitative process whereby our speech mechanisms support the thinking process as a peripheral concomitant. In this controversy some have indicated that the relationship between subvocal speech and learning is such that suppression of subvocal activity should result in less rapid learning and reduced comprehension (Ribot, 1879). Opposed to this conception is the belief that laryngeal muscle activity actively interferes with covert learning processes, and thus suppression of such covert speech would facilitate speed and understanding (Dodge, 1896).

The critical assumption here is that if covert speech processes do cause interfering effects, then reduction of laryngeal activity should allow faster interpretation of the written work and greater capability of synthesizing and comprehending the text (Hardyck & Petrinovich, 1969).

The question arises as to whether this process of understanding the written word without peripheral concomitants opposes a behavioral interpretation of thinking. Though this paper was not designed to argue the merits of either centralist or peripheralist positions, it will be noted here that Watson's (1924) interpretation of "thinking," i.e., the occurrence of covert language responses, is not the only behavioral explanation available to describe the phenomena. For if Skinner (1957) is accurate in stating that there is no unique subclass of stimulus-response laws that correspond to what we traditionally call "thinking," then covert vocal concomitants may be only one of many and varied physiological representatives that may or may not play an integral role in silent mentation.

Gibson (1975) notes that the rate of adult speech is around 170-200 words per minute. This reading rate is not too far off from Tinker's (1962) estimate of casual reading speed at between 200 to 300 for most educated adults. Similarly, Landauer (1962) found that there was essentially no difference in the rate of implicit speech versus that of overt speech. His subjects were instructed to speak aloud various numbers and word combinations while their rate of speech was timed. They were then instructed to repeat the same series of words and numbers silently and to push a button upon completion of the task. Results indicated a near perfect correlation between overt and covert rates of speech. This information is consistent with later findings by Hardyck and Petrinovich (1966). How then does reading speed ever become faster than overt articulation? And what is the process of transition, if any, between overt and covert reading? Several theories have been proposed to account for such transitions.

During the early development of reading in primary school, emphasis in reading is typically oral. Thus, we see a constant pairing of the oral verbal stimulus with the written word. Over time, the strong associations are built between speech motor habits and the written text. Cole (1947) lists five sequential stages of reading development as they relate to the subvocal tendency. She indicates that children initially say aloud or whisper almost every word. This stage is followed by whispering exclusively. Later, lip movement is seen but no sound is heard. Then the reader advances to the point where no lip movement is seen but throat movement may be detected with the fingers. A last stage not listed by Cole could further be described, namely that point where reading has developed to the extent where no throat vibration can be felt with the fingers, yet sophisticated electronic recording equipment might still detect laryngeal movement. As to whether it is possible or desirable to completely eliminate all laryngeal activity while reading difficult material is still a matter of speculation. This point is further elaborated on by Dolch (1948):

> First, the lips find it impossible to keep up with the reading but the other speech organs still move. Then the tongue ceases to move but movement still goes on in the larynx. The final stage would be for the larynx movements to cease altogether, but there is much debate as to whether this ever happens with many individuals. (pp. 78-79)

Harris (1948) is of the opinion that lip movement, prior to the third grade, facilitates the reading process. However, he believes that if the habit persists past the third grade, it begins to have a detrimental effect. Gates (1947) is of the same opinion. He states that:

> In the primary grades pupils are likely to articulate words quite definitely and fully in their silent reading. In the early stages this habit does no harm for the reason that the pupil can articulate words quickly as he is capable of reading them. The habit, however, may become fixed and definite, complete articulation of the word may persist. In any case, time is taken to produce, in some form, the motor organization or the sound of the word. A child subject to any of these habits cannot read more rapidly than the speed with which he can articulate. When his silent reading reaches that level it is likely to remain until the habit of articulating or imagining the word sounds is eliminated. (pp. 91-92)

It seems unlikely that the "habit of imagining the word sounds" is ever entirely eliminated. However, what might be partially reduced is the tendency toward articulation or subvocalization (Ninness, 1974). This may happen spontaneously in some readers or may be facilitated by the use of electromyographic feedback (Hardyck & Petrinovich, 1969).

Such feedback will be given further consideration as this paper develops.

One reading expert (Dolch, 1948) recommends that the reader be exposed to vast amounts of relatively easy material. Such reading allows the child to eventually drop out the use of lips, tongue, and larynx, in that order, as he becomes increasingly superfluous to the reading process. Hollingworth's (1933) cue reduction theory seems to fall in line with those who believe increased reading skill negates the need for subvocalization. Cue reduction is defined as the elimination of superfluous responses during the progressive refinement of a particular skill. Thus the need for auxiliary kinesthetic, proprioception decreases with increasing reading sophistication. Such theories have long been held at least implicitly by many reading specialists. Gibson (1975) notes that attempts to eliminate subvocalization have been tried with varying success where the rate of reading is decreased due to subvocal interference. But she points out that in other cases there has been often an attempt to have readers deliberately subvocalize in order to slow down the reading rate and concentrate on the text. In this case the act of subvocalization is not only a mechanical device that slows the reading rate but has the advantage of being a redundancy for another modality. She indicates that such reading specialists see subvocalization not as a course of poor reading but merely a symptom. Thus, Tinker (1962) offers the following suggestion to those who perform remedial reading:

> In general . . . throughout elementary school, the emphasis should be placed upon development of comprehension, word meanings, and concepts. If this program is properly carried out, there will be little need for specific training in speed of comprehension for most pupils. Any class-wide program for "whipping up" the speed of comprehension represents misplaced emphasis. When the program of teaching is adequate, speed will tend to take care of itself. When material is within the child's capacity to understand, the more clearly he comprehends it, the faster will his rate of progress tend to be. (p. 96)

Contrasted with the suggestions of Tinker (1962), speed reading programs attempt to increase the rate of reading by not only eliminating subvocalization but by teaching the reader to read down the center of the page without giving full attention to any specific word in the context of the text (Graf, 1973). In this way all words are seen but none are dwelled on and no regressions are made. Speed reading has evolved into a national, if not international, fad in recent years. Private speed reading institutes, individual texts, and even authorized university speed reading courses have been promoted in an effort to increase and expand man's capacity to acquire knowledge. In an age of rapid cultural transition, it has become increasingly important to keep abreast of current events, technological developments, and educational advances. Speed reading has been heralded by many as the ideal method for quick learning. Theoretically, the attempt in speed reading is to maintain a mental attentive set which increases comprehension through a process of active construction of meaning (Whimbey, 1975).

Opposers to this technique ask how much can be retained or understood when full attention is not given to specific word meanings within the confines of each sentence. Whimbey (1975) states that:

> Speed reading cannot possibly impart comprehension of new and complex ideas, but can only provide a superficial acquaintance with topics. For many purposes, and much reading material, this may be all that is required. But more cannot be expected. (p. 97)

Contrary to speed reading practices, Whimbey states that:

> Good readers not only "hear" the words as they read and make small lip and tongue movements, but they may go so far as to whisper a difficult phrase or sentence in grasping its meaning. When this is done with an attitude of seeking understanding, the kinesthetic involvement seems to intensify concentration and fix ideas more strongly in mind. (p. 92)

Whimbey cites Dixon's (1951) report that the reading rates of 118 University of Michigan professors averaged 303 words per minute and that the average reading rate of Harvard freshmen was documented by Kolers (1972) to be about 300 words per minute. Whimbey concludes that reading cannot proceed much faster than this without loss of comprehension and that any attempt to eliminate subvocalization in order to increase reading rates above this level will cause decreases in comprehension. Research by Carroll (1964) of the Educational Testing Service further supports Whimbey's contention.

Many behavioral scientists have been most critical about the speed reader's ability to maintain comprehension while reading at rates above 500 words per minute (Graf, 1973). This is an especially questionable process in the area of reading difficult texts (Hardyck & Petrinovich, 1970). The method of reading advanced in this paper does not advocate speed reading in the traditional sense. The only aspect that is related to speed reading is the eliminating of subvocalization. But as has been documented thus far (Hardyck & Petrinovich, 1970), this is a serious area of contention. In order to appreciate the history of this contention, the reader is invited to follow the course of many of the investigations regarding the utility and function of the act of subvocalization.

Review of the Literature

Just prior to the beginning of this century, researchers started analyzing the concomitants that might play a role in some of the peripheral processes of reading. Dodge (1896) reported that his inner speech processes were not disturbed when he placed 20% cocaine solution on his tongue and lips. He commented that the anesthetizing effects on his speech musculature must have been independent of his central thinking processes. Curtis (1900) was one of the first to demonstrate a method of measuring laryngeal activity. The components of his crude apparatus were simply two tambours. One was attached to the larynx while the other wrote on a smoked surface of a kymograph drum. Subjects were asked to recite familiar poems silently, whisper the same poem, and to try to maintain a blank mind. Recordings from these three operations were compared, and it was found that a difference in these types of behaviors could be traced on the smoked surface of a revolving drum. This experiment seemed to establish that speech muscles were often involved in mental recitation. Courten (1902) was able to confirm Curtis's findings with a different procedure. He placed an inflated rubber bulb in the mouth of his subjects and was able to monitor tongue movements. Again, strong correlations between active thinking and speech musculature were observed. Using a Verdin Laryngograph, Perky (1910) recorded three subjects when they were (a) producing images of memory, and (b) producing images of imagination. She found 84% of 155 memory images produced laryngeal potentials, while 91% of 214 imagination images did not produce such activity. She concluded that images of memory were associated with productions which had the effect of making speech muscle movement. Another early study conducted by Wyczoikowska (1913) involved the use of kymograph to record tongue movements during thought. In this case a flattened wine glass was used as a receiver, and the information regarding subvocalization was projected via a Marey tambour with an elongated pen. Subjects were required to insert their tongues in this glass which would in turn affect the tambour by means of a rubber tube. Despite the awkwardness of this mechanism, Wyczoikowska indicates differential curves registered when subjects rehearsed a familiar verse silently, covertly said complicated words, remembered melodies, and even listened to various sounds under hypnosis. The results seemed to indicate a synchronization between thoughts and tongue movement. This analysis was further corroborated by the introspection of the subjects. Most affirmed an awareness of some tongue movements.

A systematic analysis of the effect of subvocalization on reading speed and comprehension was performed in the same year. Pinter (1913) had each subject serve as his own control when first, he read a specified amount of material while timed, and second, practiced reading similar kinds of material, each subject repeating aloud the consecutive digits of 13, 14, 15, and 16. This process of repeated overt speech during reading was an attempt to reduce as much covert speech as possible. Of special importance to note here is the fact that subjects continually "practiced" reading over many tested and timed trials before becoming proficient at this method of silent reading. For all subjects a steady decrease in time to read occurred, while the comprehension level steadily gained. The only question Pinter leaves is whether the habit of subvocal articulation will not tend to reoccur. He states, "It is questionable whether such a habit, that is of such long standing and so deeply rooted in the adult, can be permanently overcome" (p. 153).

Further analysis of the role of subvocalization came from Morgan (1916). He found that interfering auditory stimuli produced breathing changes in subjects who were reading. He interpreted this as an indication of increased subvocalization tendencies during distraction. A quite different conclusion was reached by Reed (1916) the same year, who also used breathing as an index of subvocalization. Reed had subjects place a drum, covered by a rubber condom, in their mouths. Changes in air pressure exerted against this drum were recorded on a kymograph. Any changes in breathing, tongue movement, and silent speech were thus recorded. He obtained measures on breathing while relaxed, silent reading, writing, whispering, and reading aloud. Reed concluded that silent speech (i.e., the movement of the tongue and breathing changes as a function of such speech) was a highly idiosyncratic behavior wherein some subjects used this practice consistently and others, seemingly, not at all. Reed further analyzed the need for such silent speech among those subjects who seemed to use it most. He tested these subjects' comprehension when they were made to recite a repetitive phrase over and over as they read some other material. Again, he found diversified results. This task seemed to interfere with the reading of some subjects but apparently had no effect on others. He concluded that inner speech was not a relevant variable in comprehension or rate of reading. These results are obviously inconsistent with those Pinter (1913) had reached 3 years earlier. Perhaps the differences can be accounted for by the differing methodologies. Pinter had all subjects practice repeating irrelevant verbalizations over many trials as they read, while Reed simply took his data from the results of a single test. The procedure of practice could quite possibly have made all the difference in the conclusions. However, insignificant results were again obtained in a study of an attempt to eliminate silent speech. O'brien (1921) had children from 20 schools in Illinois participate in a massive experiment. Subjects were given verbal exercises that would supposedly eliminate subvocalization while a control group was given no instructions. Results indicated no detectable differences between groups.

Thorson (1925) wrote an elaborate criticism of previous efforts to obtain data on internal speech She particularly objected to the use of the rubber bulb or drum in the mouth technique, as it reacted to too many internal changes, including all tongue movements. She further specified that previous apparatuses had been too uncomfortable for the subjects, and as such, interfered with normal thought processes. However, it is highly questionable as to whether her apparatus made any significant improvement in the area of comfort. She used a metal suction cup attached to the tongue, which was in turn attached to a wire. From here movement was transmitted through links and bell cranks, and writing was eventually accomplished with the use of light bronze springs. In order to determine the parameters of silent speech, she had subjects perform mental multiplication, the reading of nonsense syllables, and typical textbooks. All such behaviors were performed aloud, at a whisper, and silently. She concluded that tongue movement might be independent of verbal thought and that such tongue movements are poorly synchronized with the same movement performed in overt speech.

Regardless of Thorson's admonitions, Scheck (1925) again used the rubber bulb in the mouth technique. Connecting the bulb to a pneumograph, data was tabulated in the usual fashion on a kymograph drum. Contrary to Thorson, he found covert tongue movements to be quite highly correlated with similar overt verbalizations. He also indicated that such activity was increased when subjects were under stress.

The most imaginative and sophisticated nonelectric device for recording subvocalization was implemented by Rounds and Poffemberger (1931). A Baily face mask and valves and Douglas air bags were used to collect expired air. A tube leading from the mask was connected to a large tambour with a movable rubber membrane. Expelled air was thus affected by the chest tension, vocal chord movement, and the movement of the tongue, as well as any change in position of the mouth. The experimenters indicated that implicit speech might involve any or all of these reactions. Thus, subjects were able to be measured at rest, during thought processes, and while speaking. Likewise, the curves for these activities were compared. Checks for such comparisons were made by analyzing the records of persons who were deaf-mute from birth. Breathing records indicated increased tendencies toward laryngeal movement while subjects were performing mental work. No such tendency was noted by subjects who had been deprived of speech.

Looking back at most of these early studies, one gets the impression that researchers were often incapable of really obtaining reliable data. Difficulties in all these research techniques revolve around the use of cumbersome equipment of high inertia. McGuigan (1970) states that:

> As a general comment on these early studies, it is quite apparent that controls, by today's standards, were inadequate, that the apparatus was quite crude, that findings were not evaluated statistically, that conclusions were often justified merely on the basis of selected sample traces, that a small number of subjects was often used, and so forth. In view of the lack of experimental sensitivity, it is therefore surprising that positive evidence of increased oral activity was ever obtained. (p. 314)

Jacobson (1931) was the first to employ the use of needle electrodes for the electrical recording of speech. He inserted fine platinum iridium wires into the tongue and under the mucosa of the cheek. These needles led to a string galvanometer which had the potential magnified 600 times. Vibrations of the string were then constantly photographed on a graded screen. Subjects were asked to imagine counting, talking, or to consider some abstract concept. These subjects had all been given previous training in Jacobson's method of progressive relaxation wherein individual muscle groups were placed under verbal control for relaxation. Jacobson found strong synchronization between potentials achieved via whispering and those of silent speech, the latter being approximations of the former. Also, Jacobson emphasized that his subjects, who were trained in introspection, all reported subjective feelings of tenseness in their tongues and lips during the experimental phase of silent speech.

Again, Jacobson (1932) reported similar research. Once again he had his subjects trained in progressive relaxation and subsequently fitted for needle electrodes in the tongue and upper lip. This time he had them imagine counting, asking a friend for a date, recall a poem, multiply, and think of abstractions like eternity and electrical resistance. For five out of seven subjects the data indicated increased potentials during most of these activities. The remaining two subjects were incapable of relaxing under the experimental conditions, thus their data was not available for analysis. Most interestingly, Jacobson found muscle potentials were specific to the areas which the subjects imagined they were using. The imagining of arm movement brought about increased recordings from the arm to the exclusion of any oral activity.

An entirely different approach was employed by Bird and Beers (1933). They tested the effect of inner speech on reading rate by having their subjects read with an attempt toward subvocalizing and an attempt to perform as little subvocalization as possible. Reading rates were then compared, and it was found that maximal inner speech apparently slowed reading rate. However, Edfeldt (1960) criticizes this study:

> In the first place, we do not know whether or not this obligatory maximal or minimal inner speech has the same effect as spontaneous forms of the same phenomenon. Further, we do not know whether these obligatory laboratory forms of the phenomenon, produce on reading ability, effects wholly due to the fact that they constitute a totally new element in the reading situation. (p. 89)

Max (1937) performed an especially provocative and relevant study in which he recorded the arm and finger potentials of deaf-mutes. It is recalled that such people have the locus of verbal control in the upper appendages as they communicate via sign language. Comparisons were made between a group of 18 such handicapped persons and a group of 16 normals. It was found that 86% of the mutes displayed potentials in area of the hands during complex thinking, whereas only 31% of the normals displayed such activity.

This finding further corroborates the notion that mediation of the thinking process is not necessarily isolated to particular modalities. Rather, it is probably accurate to say that any modality that an organism uses to communicate with others is also likely to be activated while communicating with the self in covert verbalization.

Still another innovative approach was implemented by McDade (1937) who made efforts to teach students to avoid the subvocal tendency by teaching first grade students reading in a nonoral fashion. Children had exposure to written word and picture associations rather than written word and oral word associations. Early indications were that this process was more effective in increasing reading scores related to speed and comprehension. However, similar procedures developed by Buswell (1945) showed only minor differences in the tendency to subvocalize, and there were no reported indications of differences in reading ability as measured by comprehension scores on reading rates.

One rather parsimonious researcher (Cole, 1938) attempted to confront the problem by simply having her subjects chew gum while reading. This, she believed, would interfere with any subvocal speech process. Pushing her research further, she requested her subjects to actually hold down their tongues with the use of their fingers. Results of this research were rather inconclusive.

Not unlike the Bird and Beers (1933) study, Fryer (1941) tested the effect of forced articulation on comprehension. Using mathematical problems, he had subjects articulate and suppress articulation during the operations of addition, multiplication, and subtraction. His findings indicate that both extremes of articulation and suppression of subvocalization have a detrimental effect on comprehension. However, the forced articulation seemed to be less deleterious than forced suppression. Again Edfeldt (1960) criticizes this type of study involving subject control of inner speech through simple willpower. It is his feeling that both the Bird and Beers study and the Fryer study indicate that the conscious expression of subvocalization tends to cause some form of interference. In the case of the Bird and Beers study, Edfeldt states that the possibility exists that if the maximal inner speech were prolonged outside the laboratory setting, such inner speech might become less interfering and more spontaneous. However, Edfeldt's criticism and comparison of the Bird and Beers study and the Fryer study seems somewhat misleading. The Fryer study used comprehension as the dependent variable, while the Bird and Beers used reading rate as its criterion. The comparison of two studies with completely different dependent variables seems to only further confuse the issue.

By 1958, most significant researchers in the area of subvocalization were relying on electronic instrumentation as initiated by Jacobson (1931). Using needle electrodes inserted into the vocal and posterior cricoarytenoid muscles by indirect laryngoscopy and into the mylohyoid muscle through the floor of the mouth anterior to the tongue, Faaborg-Anderson and Edfeldt (1958) found that an increase in electrical potential was found during silent speech. Reading both in native Danish and foreign Swedish, subjects were recorded during silent reading,

reading aloud, and during a rest phase. Results indicated the posterior-arytenoid worked in paradoxical fashion. That is, as the tendency to vocalize or subvocalize increased, this muscle became inhibited, but during voice rest the muscle became activated. Thus, the vocal and mylohyoid muscles were probably the best indicators of subvocal activity. Potentials from these muscles were consistently active during both silent reading and reading aloud in Danish and Swedish. Results also indicated that subjects familiar with foreign Swedish were not more inclined toward subvocalization while reading it than native Danish. However, in subjects unfamiliar with Swedish, the tendency to subvocalize increased during that silent reading.

Edfeldt (1960) further elaborates on his early research with Faaborg-Anderson. Edfeldt states that he originally tried the old method involving the mechanical use of condoms on each side of the tongue. This procedure was somewhat more sophisticated than all such previous experiments involving tongue pressure against various inflated devices in the mouth, in that Edfeldt had the aid of modern amplifying devices. But by his own admission, such techniques are utterly futile. This is a strong indication that all such previous experimentation, primarily done prior to Jacobson (1931), was indeed unreliable. It was primarily for this reason that he and Faaborg-Anderson initiated the use of electromyographic recordings.

In the research conducted by Edfeldt (1960), three experimental hypotheses were formulated:

1. Good readers engage in less silent speech than do poor readers.

2. The reading of an easy text results in less silent speech than does the reading of a difficult one.

3. The reading of a clear text results in less silent speech than does the reading of a blurred one.

To test these hypotheses, Edfeldt (1960) again inserted needle electrodes deep into the mylohyoid musculature to record 87 students who were reading silently. In general, the results of his experiment confirm these hypotheses. There were very clear and significant indications that low reading scores and increases in silent speech were correlated. Likewise, high reading scores generally coincided with less subvocal behavior. It was also shown that even excellent readers with little tendency toward subvocalization began to perform subvocalizing when the reading material became very complex. Experimental hypothesis 3 was less clearly confirmed. There was some general tendency for blurred texts to produce more subvocalization in readers, but this was apparently not statistically significant. However, Edfeldt points out that some good readers display no recordable subvocalization during the reading of most texts and display only slight tendencies when the material becomes exceptionally difficult. Therefore, Edfeldt states that "it is then impossible to view silent speech as a habit detrimental to reading" (p. 152). He suggests that subvocalization is more likely a symptom of some reading problem rather than a cause. He regards attempts to eliminate subvocalization as a form of remediation to be totally fruitless and possibly even detrimental to the reader. However, it is important to note that Edfeldt's experiment did not deal with the direct practice of reading with electromyographic feedback to the subjects. Nor was there any attempt to test the effects of ongoing practice of reading with the maintained elimination of subvocalization, through the use of feedback. The question, then, still exists as to whether some individuals might conceivably benefit from long-term practice of reading with the subvocal tendency held to a minimum.

Blumenthal (1959) tried a different approach to the problem. He specifically selected 11 of 89 possible subjects who showed clear and extreme tendencies toward subvocalization. His intention was to show a correlation between word class and the subvocal tendency. McGuigan (1970) criticizes this selection bias despite Blumenthal's restricted criterion. But regardless of external validity, Blumenthal found that his subjects displayed increased amounts of subvocalization while imagining such activities as licking a stamp, sucking a lemon, and imagining repeating words back to the experimenter. Likewise, the tendency increased while just listening to words. More to the point of the experimental purpose was the finding that tongue responses increased more for the covert emission of lingual words than for labial words.

Along the same lines, Bassin and Bein (1961) recorded electromyograms from the lip and arms of subjects who were required to perform verbal tasks. Increases in potentials were correlated with the difficulty of the tasks until the tasks became so difficult that they were unsolvable. In addition, they tested some subjects with speech impairment. It was found that when these subjects were asked to mentally pronounce a word they were incapable of actually articulating, that speech potentials dropped out while arm potentials increased. Bassin and Bein interpreted this as covert attempts at writing the unpronounceable word.

Still in the same vein was research performed at about the same time in Russia by Novikova (1961). She used electrodes consisting of:

> Small suckers inside which were fixed a hook-shaped loop of silver wire, 5mm in diameter. The bent surface of the hook came into contact with the tongue

> and allowed potentials to be led off from it. A 0.2mm enamelled wire soldered to the hook was taken to the input stage of the amplifier. The sucker itself consisted of the end of the rubber teat of a glass pipette stretched over a flat metal ring having external and internal diameters of 1.2cm and 0.6cm. For bipolar recordings, two of the electrodes were placed on the dorsum of the tongue. (p. 107)

All this goes to further exemplify the difficulties in arranging equipment for this type of research even during a time when electronics were coming in vogue.

The experimenter was able to determine, as in previously described studies, that acts of problem solving, memorization of words, and silent counting produce detectable muscle potentials on the electromyograph. Further, it was demonstrated that these potentials increased proportionally with the difficulty of the problem. A few subjects even produced potentials while listening to the problem. Further, it was indicated that literacy was a variable in the subvocal tendency. Those with the least education tended to subvocalize the most.

The most interesting aspect of this research, as with the Max (1937) study, revolved about the testing of deaf-mute children who had been taught both oral and manual communication. These children displayed increases in both tongue and finger movement during the various problem-solving tasks.

Studies pursuing the developmental course of subvocalization are particularly relevant to understanding the phenomena. McGuigan, Keller, and Stanton (1964) analyzed chin and lip amplitudes of children at various ages during a prereading and a reading period. Potentials showed orderly increases from one period to the next. Investigations with college students displayed the same increases from rest to reading. Pneumograms likewise indicated increased respiration rate during silent reading for both groups. However, audible subvocalizations were only picked up on the microphone recording of children. College subjects displayed no such audible subvocal behavior. Obviously, the extent of subvocal activity had decreased substantially for the more adept college readers.

The pivotal study in electromyographic research occurred when Hardyck, Petrinovich, and Ellsworth (1966) introduced the concept of feedback to the study of subvocalization. Using the increasing sophistication of electromyographic technology, these researchers literally taught subjects how to control their subvocal behavior by giving them constant feedback from their laryngeal apparatus during reading. Subjects practiced reading while trying to keep feedback, in the form of static over earphones, at the lowest possible level. They reported that after one session, in fact, after one 5-minute period, subvocalization was completely extinguished for many subjects. Furthermore, they stated that after a period of 3 months no remission was indicated.

Equally phenomenal was the fact that this was the first occasion in which researchers had reported positive effects using surface electrodes for the electromyogram. Hardyck placed surface electrodes on the carotid cartilage, near the larynx of his subjects, so that any laryngeal activity could be detected.

Subjects practiced alternating relaxation with silent reading at various short-term intervals. This brief experience was, according to Hardyck, Petrinovich, and Ellsworth (1966), sufficient to extinguish subvocalization in all subjects. Hardyck et al. admits that the total and apparently complete extinction of such an overlearned response as subvocalization, in so short a time period, to be somewhat remarkable, and then attempts to explain this rapid extinction on the basis of conflict with a second, even more strongly learned response.

> Such a second response is the ability to make fine motor adjustment of the speech musculature on the basis of auditory cues. Exactly this response is involved under conditions of feedback of laryngeal EMG activity. (Hardyck et al., 1966, p. 1468)

While the research conducted in this experiment is of exceptional value, there are a few problems associated with the author's explanation of the phenomenon. Hardyck does not explain why making fine motor adjustments to an auditory cue is a stronger overlearned response than subvocalization. The assumption that this is the case is open to serious theoretical question. But a more perplexing question is why Hardyck et al. (1966) chose to call the elimination of subvocalization, via auditory feedback, an extinction procedure. Extinction is operationally defined among learning theorists as the removal of a response from an organism's repertoire through withdrawal of reinforcement. It is not clear that the act of subvocalization constitutes any inherent or secondary reinforcement; nor is it clear that the placement of a subject under the influence of another form of stimulus control (in this case an auditory signal) constitutes withdrawal of any reinforcement. What does constitute secondary reinforcement is the biofeedback signal itself. From an operant perspective it seems likely that subjects in Hardyck's experiment simply came under stimulus control as a function of the experimenter's instructional set and the secondary reinforcing value of the auditory signal. It is popularly understood that biofeedback signals can be a form of secondary reinforcement. Racklin (1976) points out that secondary reinforcers can facilitate two functions: One is to signal to a subject that he has made the correct response, and the second is to indicate that reinforcement is forthcoming. It seems likely that the auditory feedback in Hardyck's study served the particularly important role of acting as information for the subjects that correct responses were being made when the tone receded. Thus, subjects quickly came under the control of such a tone.

Probably the most telling criticism of this study is, that while Hardyck claims that the elimination of such subvocalization should be "valuable in treating some reading problems," he does not validate this statement by showing any reading proficiency attained by his subjects. It is left to the reader to infer only particular advantages that might have been gained from such treatment. However, later studies by Hardyck and Petrinovich do place some emphasis on such validation (Hardyck, 1969; Hardyck & Petrinovich, 1970), but the information given in these latter studies is somewhat inconsistent.

However, even before he had an opportunity to clarify this issue, information formulated by McGuigan (1967) was at variance with Hardyck's original study. McGuigan suggests that Hardyck's 1966 study may have confounded an independent variable by allowing subjects to acquire a set on which verbal behaviors might be expected of them. Many subjects, eager to please the experimenter, could easily ascertain the examiner's intentions and attempt relaxation of vocal areas irregardless of feedback operations. To examine this possibility, McGuigan had three subjects hook electrodes on their vocal apparatus and chin-lip areas while reading and gave no feedback to two subjects while feedback was given to a third. The curves for all three subjects are practically identical. All show rapid reduction in EMG amplitude for the vocal apparatus hookup. This effect occurred regardless of the fact that subjects were in no way intentionally made aware of the behavior expected of them.

Hardyck (1969) replicated his earlier research and found some rather paradoxical results. He indicated that for college age students all subjects were capable of overcoming subvocalization within 1 hour. Further, no remission was detected on posttests even over several months. However, he found that reading rate did not improve as a function of this reduced subvocalization and that high school students treated in the same study required two sessions to eliminate subvocalization. Also, this group had a strong tendency toward remission. He points out that eight of 13 of these subjects reverted to their previous reading tendencies of subvocalization. But he found a critical variable with regard to those who tended toward remission. These subjects had IQs of only 94 while those who maintained the elimination of such speech muscle activity averaged 113. Further testing of these subjects was equally illuminating. Seven-month rises in reading level on the Gates Reading Survey were found for the nonreverting subjects, while those who reverted gained only 3 months. As Hardyck points out, these results indicate some positive benefits from such training. However, it appears that only higher level readers show such benefits. This particular study did not investigate the relationship between increases in reading scores as related to specific ranges of difficulty.

One particular point from Hardyck's 1969 study bears further consideration. In this publication he points out that no individual with strong speech muscle activity read faster than 195 words per minute. Poulton's (1961) data contradict this information. He specifies that subjects are capable of reading over 400 words per minute aloud (an obvious case of considerable speech muscle activity). The discrepancy here may be in what subvocalizers tend to do rather than what they are capable of doing. That is, faster rates of reading than 195 w.p.m. may be possible while subvocalizing, but such reading may produce something of a fatigue effect over time. Thus, subvocalizers may tend to read slower in order to place less strain on the vocal apparatus when doing extensive reading. Such a conjecture is supported by further findings from Hardyck (1969) in which his subjects who were trained to overcome subvocalization claimed greater ease in reading and less fatigue when reading for long periods of time.

Still, Hardyck did not refute the criticism of McGuigan. No attempt was made by Hardyck to show that reductions in subvocalization were purely a function of EMG feedback exclusive of subject's attempt to cooperate with the experimenter. Later, however, Locke (1971) reported his efforts to discover whether reduction of subvocalization actually existed independent of the subject's intentional manipulation. He used naive subjects with electrode placement at various irrelevant positions over and above the throat. EMG records indicated significant amplitudes during silent reading of high labial material.

But McGuigan (1971) was still not satisfied with the information reported by Hardyck. He wanted to test the longevity of the elimination of subvocal behavior with EMG feedback despite Hardyck's repeated assurances that two studies revealed relatively permanent effects as documented by 3-month follow-ups. Using six subjects who were high amplitude subvocalizers, he attached electrodes to the lips, tongue, and chin to obtain subvocal activity and then to the legs, neck, and arms to obtain measures on non-speech-related musculature. This was also done in order to maintain the subjects' naivete regarding the procedure. All subjects in the experimental condition were capable of reducing feedback, and thus subvocalizations, only when told the relationship between the tone and the chin, lip, and tongue activity. This does not conflict with any of Hardyck's original data, but McGuigan also found that these training effects were short-lived. McGuigan states:

> From the first trial after the experimenter removed the tone, subvocalization returned to the pretest levels. There was no evidence that any of the six subjects reduced subvocalization without external reinforcement. (p. 214)

By external reinforcement it is assumed that McGuigan means the auditory feedback signal. This information does directly conflict with Hardyck's 1966 and 1969 results. Further inconsistencies found by McGuigan include the finding of immediate increases in reading rate associated with the temporary reduction of subvocalization.

Under the bombardment of conflicting data from many sources, Hardyck and Petrinovich replicated their earlier studies but this time incorporated some new variables. They worked with 18 freshman students from a remedial English class; the reading materials were two essays judged by the English instructors to be similar in interest but to vary widely in difficulty of comprehension. One group read while EMG recordings were taken from the laryngeal area, the chin and lips, and the right forearm flexor. A second group was to keep the audio signal from the EMG off, as in their previous studies. The control condition was the same as the feedback condition except that the subject had to keep off the acoustic signal generated by muscular activity in their forearms. Hardyck and Petrinovich found that feedback from the laryngeal apparatus to the subjects who were subvocalizing while reading difficult material reduced the comprehension level of that group when those subjects made attempts to eliminate that subvocalization via the feedback stimulus. Other groups receiving muscle feedback from chin-lip activity and forearm movement were unaffected by the feedback with respect to comprehension of difficult material. However, all groups were comparable in understanding relatively easy texts. The experimenters took this evidence as confirming a mediation theory of reading comprehension; that is, association between speech sounds and proprioception made in the process of producing these sounds and the words in the written passage that are seen visually. Accordingly, this proprioception serves as a stimulus support for further responses. These complexes thus act as a mediator when the individual is first learning to decipher written symbols and later are useful in comprehending a difficult text. But Hardyck also found that subvocalization can at least be overcome without detrimental effect when the subject is reading simple material. He explains this discrepancy by proposing that the proprioceptive cue eventually becomes a redundant stimulus. Accordingly, only the visual stimulus is needed to facilitate understanding when the material is not too difficult. Thus, subvocalization would only be called into use when a specified amount of redundancy is required to decode difficult material.

Even McGuigan (1964) study does not necessarily conflict with this interpretation. For he had found that when subjects were given feedback via electromyograph on chin-lip movements, this produced no more tendency to subvocalize while reading French than reading English, their native language. Seemingly, complexity and unfamiliarity were not critical variables which determine the need to subvocalize in this experiment. But, note that feedback was given from the chin and lip areas! Hardyck also found no decline in comprehension with feedback from this area, but did find decrements in comprehension when the larynx was used as the feedback target. Apparently, this is a more critical location for mediation through proprioception.

Other evidence for this mediation theory of comprehension is supplied by an experiment conducted by Mechanic (1971) which indicated that learning increased with the amount of pronouncing as opposed to just viewing the visual configuration of words. The subjects who were told to merely study the word's visual attractiveness did significantly worse than that group which was told to study the attractiveness of the sound of a word pronounced. However, since the former subjects were not expected to attend or concentrate on the words, it is unlikely that they would be forming the same kinds of impressions as those who actually read the material aloud. At any rate, such viewing of words cannot really be fairly compared with an active process of reading with or without subvocalization. For even Hardyck's 1970 study indicated that nonsubvocalizing readers of light material comprehended at about the same level as subvocalizers.

Aarons (1971) again attacked the question of the longevity of the effect of EMG training on subvocal behavior. He found maintained reductions in subvocalization with both high and low subvocalizers when given EMG training via feedback from the speech musculature. Gibson (1975) feels that the inconsistencies between this data and McGuigan's (1970) are not mysterious. She states that:

> When subjects are told that they can reduce their subvocalization and become better readers, auditory feedback of speech muscle activity has a rapid and persistent effect. McGuigan's contrary results seem due to the differences in instruction and the motivation of the readers. (p. 345)

Gibson seems to be saying that some form of intentional set maintained by those readers in Aarons' study accounts for the longevity of the elimination of subvocalization via feedback. However, she does not elaborate on why intentions should suddenly be a relevant variable after feedback when it was not one prior to feedback.

Aarons (1971) offers more in his study than conflicting data. He elaborates on the physiological components of subvocal behavior. He points out that for studying amplitudes produced from silent reading, location is of major importance. He explains that covert reading corresponds to incipient, fractional articulatory movements or low-level isotonic muscle activity. During speech, adductor muscle activity increases impulses of the larynx while decreasing abductor muscles. In covert speech cricothyroid, interarytenoid, and lateral cricoarytenoid are abductors which increase laryngeal function. The greatest amplitude for covert speed using EMG measures of the vocal and mylohyoid muscles are found to be time-correlated and concomitant with an inhibition of activity in the posterior cricoarytenoid muscles (Aarons, 1971).

Isotonic functions are controlled by exterior feedback cues, while internal cues direct isometric laryngeal activity. Since general levels of laryngeal tension facilitate a certain amount of isotonic function, EMG feedback readings probably pick up a constant combination of both isotonic and isometric flexation. However, the isotonic activity of subvocalization is of a more distinct and audible cue in the feedback system such as to allow recognition from the background isometric and intrainstrumental static.

Sokolov (1972) conducted a number of experiments in which subjects translated English to Russian. Using Russian University students of varying ability, he had reading translations interfered with by clamping the tongue between the teeth, enunciating the syllables la-la, and reciting a stanza of poetry. He counted the correct number of semantic units and found that tongue clamping recitation of nonsense syllables had little effect but reciting poetry did interfere with the speed and accuracy of translating. In addition, he also carried out EMG research during the translations. Locations included the tongue and lower lip. He found wide individual differences in electrical activity. He notes that on occasion some subjects reveal little if any subvocal activity while reading unless given explicit instructions regarding concentration. Perhaps some of Sokolov's findings are accounted for by the fact that his electrode placement is relatively high in terms where most subvocal activity is found, i.e., the larynx. Regardless, Sokolov emphasizes his conviction that practically all thinking is correlated with some minimal mediating activity, even if it is not always detectable. He concludes that subvocalization is not strictly confined to reading or even just verbal problems. He proposes that vocal responses occur in a variety of strenuous mental tasks, even those of a spacial, nonverbal type. This position is particularly curious since some of his own data indicate individuals who show little or no tendency in this direction.

In an article appropriately named "Speed Reading: Remember the Tortoise" Graf (1973) discusses the results of his investigations with speed readers. College students were pretested with a wide range of texts from easy to difficult. After spending several weeks in a speed reading course, they were retested. While expectedly the reading rate for easy and difficult material increased, comprehension showed some rather drastic decrements. On an average, while speed accelerated 221%, comprehension dropped by 39%.

The kinds of increases in reading speed typically reported by researchers of EMG feedback have been comparatively modest. The possibility of speeds exceeding 1000 words per minute have never even been given serious consideration. On the contrary, 30% increases in reading rate would typically be considered quite an achievement, particularly if no tendency toward remission were observed.

It is important to note, in addition, that there has never been any suggestion by EMG researchers that subjects should change their reading patterns in order to achieve increases in rate. In fact, rate increases, in and of themselves, are typically not even mentioned to the subjects. The only factor responsible for rate increases with EMG training is the isolated elimination of the subvocal tendency.

The latest and possibly most significant research conducted in this area is by Bergering (1976). He investigated two parameters: (a) is reducing subvocalization via EMG feedback more effective than simply asking the subject to stop subvocalizing; and (b) what effect does reduction of subvocalization have on reading rate and comprehension? Bergering used 32 students who displayed strong laryngeal potentials during the reading of light prose and 48 who showed no sign of subvocalization. For subvocalizers, feedback was more effective than just asking the subjects to stop subvocalizing. For nonsubvocalizers no significant differences were found between just asking and feedback. Further, the author states:

> The hypothesis that laryngeal motor activity during reading facilitates decoding of the text and that temporary reduction of such activity therefore would be detrimental to the reading rate and comprehension was not supported. (p. 4192)

This data is in direct opposition to conclusions formulated by such notables in this paper as Hardyck and Petrinovich (1970), Mechanic (1971), Sokolov (1972), and Edfeldt (1960). But even these authors who seemed to agree on the need for subvocalization had strong particulars of disagreements within the confines of their respective theoretical frameworks. In general, it can be said that the understanding of the role of subvocalization as it facilitates or deters the rate and comprehension of reading is in a state of flux. Gibson (1975) notes that, "This body of research is neutral so far as the value of subvocalization in reading is concerned" (p. 349).

Major discrepancies in conclusions include Hardyck and Petrinovich's (1969) results which indicate that EMG feedback has a beneficial effect on reading scores but causes a decrease in rate. His 1970 report indicates a decrease in comprehension for difficult material but an increase in reading rate. McGuigan (1970) found no loss in comprehension but a corresponding increased reading rate. Also in opposition to Hardyck, McGuigan also found the effects of such training to be of very short duration. Mechanic (1971) concluded that subvocalization is necessary for permanent memory storage, and Sokolov (1972) found that such covert speech is a necessary part of understanding the written text. However, Bergering (1976) found no such indications. In Ninness (1974), an unpublished thesis on the effects of eliminating subvocal behavior, with EMG feedback in a single subject proved to be very effective in increasing reading speed. But the effect of EMG feedback initially caused the subject to lose much of his comprehension when reading difficult material. It was only after a long series of practice trials with such feedback that comprehension was eventually brought up to the level of prefeedback. However, after such practice was completed, the subject was reading 50% faster than baseline and maintaining about the same level of comprehension as existed at baseline.

Perhaps it is an understatement to say that the definitive study in this area has not been done. But as one reviews the literature in this area, it becomes increasingly apparent that a simple yes or no answer, as to the beneficial effects of subvocalization, is not possible. Rather, the questions should probably be: what kind of ongoing changes do we see in various individuals who are exposed to EMG feedback over a long period of time? how does their ongoing state of the emission of subvocalization change with feedback during time? and how are these changes related to reading rate and comprehension? These are open-ended questions. It is the author's opinion that answers to such complex questions are not found through the traditional hypothetical deductive models typically utilized via statistical procedures. Most of these studies previously discussed have been concerned with deductions via statistical inferences made from large groups. And as Skinner (1969) has said:

> When a subject matter is very large (for example, the universe as a whole) or very small (for example, subatomic particles) or for any reason inaccessible, we cannot manipulate variables or observe effects as we should like to do. We therefore make tentative or hypothetical statements about them, deduce theorems which refer to accessible states of affairs, and by checking the theorems confirm or refute our hypotheses. (p. ix)

But he goes on to point out that "the method tends to be used when it is not needed, when direct observation is not only possible but more effective" (p. ix). Such is the case with the current state of EMG feedback as it relates to subvocalization.

The inductive procedure as advocated by Skinner (1969) and Sidman (1960) seems well suited to the further investigation of this evasive issue. The procedure of experimenting first and letting the theories emerge inductively from the data as advocated by Sidman appears to be the only reasonable approach to a constantly fluctuating series of conclusions.

Sidman (1960), in his landmark treatise on "The Tactics of Scientific Research," points out that:

> There is a distinction to be made here between having a hypothesis and performing an experiment to test that hypothesis. We often make guesses about the outcome of our experiments--even those who feel themselves to be bedrock empiricists. But often the experiment may be planned and begun before the guess is formulated. The experiment is performed for other reasons other than to test the adequacy of the hypothesis. Nor will the outcome of the experiment be judged a success or failure in terms of its agreement or

> disagreement with the prediction. This point emphasizes an important property of experiments that are designed to answer the "I wonder what will happen if . . ." type of question. Such experiments, if they meet adequate criteria of reliability and generality, never produce negative results. (p. 8)

In the proposed experiment the author asks the question, "I wonder what will happen if I follow the data of subjects' comprehension and reading rate as subvocalization is progressively reduced over many timed intervals via EMG feedback?" What will the individual curves look like as the steady state of subvocalization is changed as a function of the independent variable of EMG feedback? How will this in turn affect reading rate and comprehension?

The subjects in the previously cited experiments had no opportunity to be continually subjected to audio feedback with difficult material over an extended time period. The possibility that further exposure to feedback might render the subject more capable of attending to and discriminating visual coded stimuli alone must be considered. It was only through practice that subjects originally learned to maintain any proficiency with the combination of auditory-proprioceptive and visual stimuli. It is not inconceivable therefore, that practice, with the visual stimuli alone, while using auditory feedback as an index of subvocalization, may be sufficient for even difficult passages.

There are a number of possibilities as to the various roles played by kinesthetic potentials for internal representative ideation. It is upon the more valid interpretation of these roles that the ultimate utility of subvocal feedback is dependent.

Method

Subjects

Five subjects were a nonrandom intentional selection of individuals who displayed distinct and acute tendencies toward subvocalization while reading.

Apparatus

Determination of the electrode sites was accomplished according to the procedure employed by the Hardyck et al. (1969) study. A monopolar placement was arranged on both sides of the thyroid cartilage, and a ground lead was situated at the lateral area of the neck. This arrangement allowed a large portion of the larynx to be recorded while permitting signals to be detected via common mode rejection. Placement of the ground electrode on the neck reduced the possibility of cardiac artifact. The Beckman bio-electrodes measure 16mm and were constructed with silver-silver chloride. The reference electrode was the same quality and dimension. All electrodes were connected to coaxial cable which shielded the signal from electrical interference in the atmosphere.

Electrical activity during subvocalization was transmitted from the laryngeal apparatus via the transducer to the Beckman Dynograph Recorder, model number R-511A. Information was first received by the Electromyographic Coupler Type 9852A, set to record in the average mode of the EMG. Preamplification was then performed by a setting of .05 millivolts per millimeter on the type 4610 preamplifier associated with the output driver amplifier, with gain set at .01. Thus, total amplification was capable of picking up electrical activity in the larynx at levels at or above .5 microvolts and displaying this activity on the chart recorder.

Interference from power lines, fluorescent lights, and noise was rejected at the input and never reached the recording pen or other output modalities. This eliminated the procedure of having to record in a shielded room.

Curvilinear chart recording moved at 1/2 millimeter per second and gave continual marking on this time event. Integrated signals reached the chart output at .5 microvolts per millimeter. Output signals were then transmitted in two directions. A DC level sensing comparator received output from the Beckman Dynograph. This comparator was continuously variable such that reference ranged between 0 and ±500 millivolts or 0 and ±5 volts DC were monitored via a voltmeter. The comparator contained an audio signal source, amplifier, and speaker which produced an audible tone when the input signal exceeded the reference level as set by the variable reference level control. The tone was continuous if the input level remained above the reference level. Thus it allowed increases in amplitude of the integrated laryngeal EMG over a predetermined rest level to initiate firing of an audio signal. This signal then indicated to the subject that he had committed a subvocal movement in his larynx.

A second output signal was received by a Hewlett-Packard Pulse Counter. This frequency and event counter continuously monitored the EMG response by counting variations above the threshold preset by the experimenter. Thresholds were concomitant with those set on the comparator and fluctuated around 1.5 microvolts on the chart recorder.

Figure 1 shows a complete diagram of the EMG instrumentation.

Procedure

The procedure followed an A_1-B_1-A_2-A_3 operant design (Sidman, 1960). A_1 consisted of baseline, B_1 was the feedback intervention phase of the experiment, A_2 represented

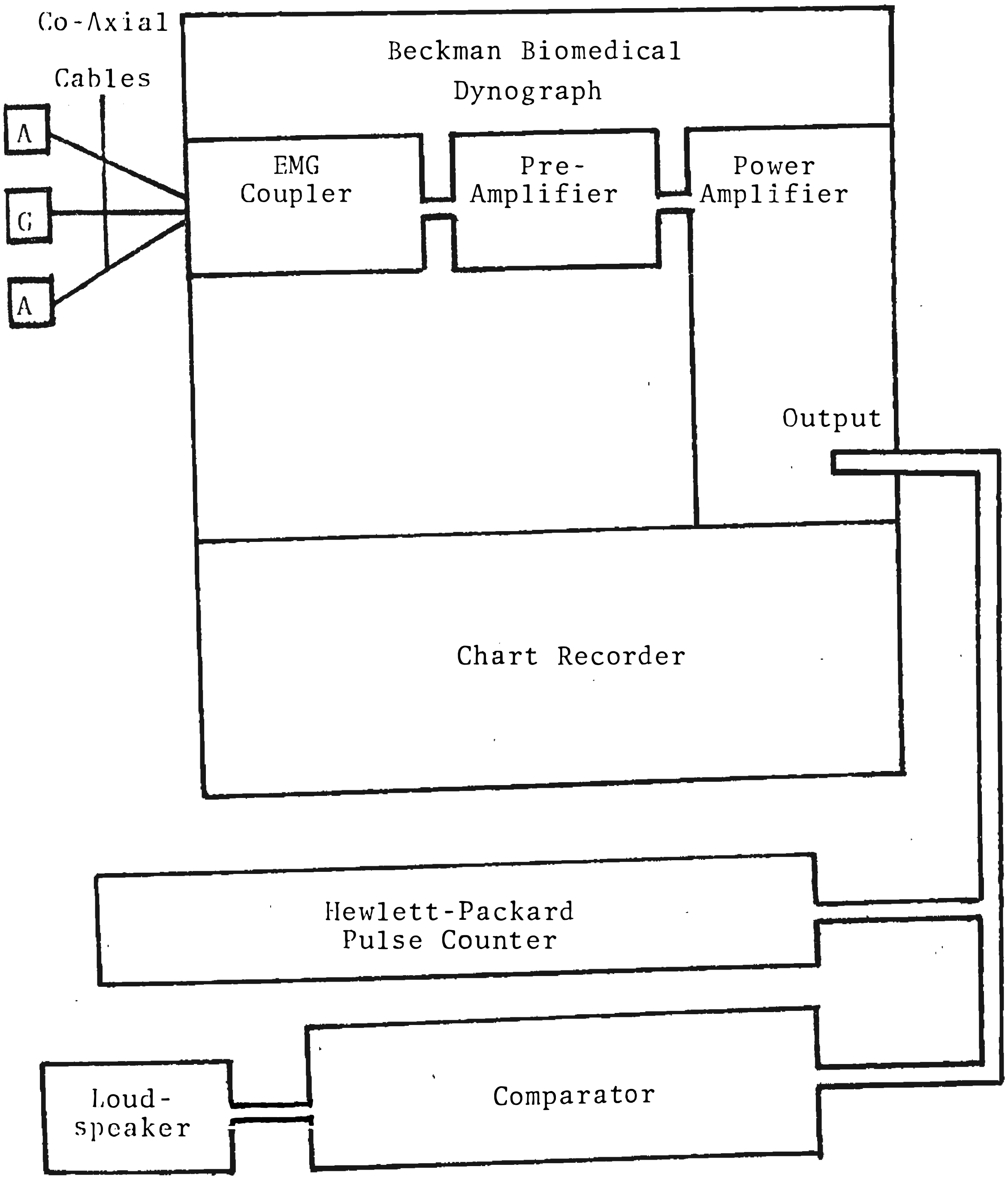

Figure 1. EMG Feedback Instrument

a return to baseline contingencies, i.e., removal of feedback, and A_3 was composed of a follow-up 1 month after A_2.

Subjects were seated comfortably at a table behind a two-way mirror. All instrumentation was hidden from view on the opposite side of the mirror in an adjoining room. The only apparatus the subject came in contact with was an audio speaker and the surface electrodes attached to his throat. Subjects were situated adjacent to the loudspeaker so they were able to attend to the audio signal which indicated increases in laryngeal activity. Lighting was arranged with a series of overhead fluorescent lights, such that vision was never impaired by shadows. Noise in and around the laboratory was kept at the lowest possible level in order to eliminate distraction of the subject while reading.

In order to prepare the electrode site, epidermal oils on the throat were cleansed with alcohol pads. The subject's skin surface over the thyroid cartilage was then lightly punctured with a series of needles protruding about 1/16 inch from a small round cork. These penetrations caused little discomfort but substantially reduced skin resistance. A location on the extreme lateral area of the neck was similarly prepared for placement of the ground electrode. Adhesive electrode washers were then attached to the plastic perimeter of the electrodes and electrolytic solution was applied in small quantities to the center of the electrodes. Placement was then arranged on the prepared sites.

Skin resistances on the electrode site tended to fluctuate from session to session, but the experiment did not begin until such resistances measured below 5,000 ohms each. Resistances above this level were judged too high for adequate measuring. When electrode sitings were satisfactorily prepared, sensitivity of the instrument was adjusted.

Baseline data began with the measuring of electrical activity in the subject's larynx at rest for determination of a threshold above which subvocalization took place. Rest was defined as that constant level of laryngeal tension which the subject exhibited as a function of sitting in the chair calmly with an effort to keep a blank mind. No feedback, either video or audio, was given to the subject at this time. The Hewlett-Packard Pulse Counter was then set at this rest threshold such that any laryngeal activity above this level was counted as subvocalization. Artifacts such as swallowing were conspicuously revealed on the chart recorder and voltmeter and were not used as data.

Reading material given to the subject was predetermined for specific level of difficulty by the Cloze test (Bormuth, 1975). During these baseline sessions, the subject was instructed to read in his normal fashion, with no special effort to read faster or slower than his typical reading pace. As the subject read for each baseline session, his subvocalization was continually analyzed and averaged over 10-second intervals. At the end of each session the subvocalization total was documented and reading rate and comprehension was measured. Reading rate was determined by the following formula:

Words per minute = A (total number of words per 5 lines)

B (that number divided by 5)

C (multiplied by total number of lines read).

Comprehension for each subject was then determined by the giving of a quiz over the material read by means of questions already prepared in the text at the end of each section.

Twenty baseline sessions were given for each subject in order to insure stabilization of subvocalization, reading rate, and comprehension.

The treatment intervention phase of the experiment began by determining rest thresholds as was done during baseline. On the first feedback session the experimenter explained the feedback mechanism to the subject and encouraged the subject to manipulate his larynx in various ways such as swallowing, speaking, whispering, etc., in order to have him become aware of minute levels of laryngeal activity necessary to fire the feedback tone. The subjects were then instructed to read material of the same type and level of difficulty as they had during baseline. They were also instructed to try to read without activating the feedback apparatus. This required that the subject maintain a level of relaxation in his larynx at least comparable to that of rest. Pilot research and previous literature (Hardyck, 1966) indicate that subjects quickly learn to inhibit subvocalization when feedback is introduced. Most learned to do this within the first 45 minutes of feedback. However, unless this feedback procedure was maintained over a long period of time, there were occasional tendencies toward remission of subvocal behavior. It should be pointed out, however, that since the feedback signal was actually a rare event after the first 45 minutes of training, that the problem of distraction via the signal during reading is somewhat eliminated.

During each treatment session that followed, subvocalization was continually measured in terms of averaging the number of spikes above rest threshold per 10-second intervals. This procedure allowed the experimenter to exclude specific intervals confounded by swallow artifacts. Spikes above threshold continued to cause firing of the audio feedback comparator over the loudspeaker adjacent to the subject. Thus, during the total treatment phase of the experiment, the subject had feedback concerning subvocal activity while reading. At the end of each session the reading rate and comprehension were determined in the same manner accomplished during baseline.

This feedback treatment continued for a specified number of sessions, depending on the length of time various individuals required to develop a stable rate of laryngeal activity, reading rate, and comprehension. All subjects were given at least 10 sessions of feedback poststabilization of these dependent variables to insure accuracy of the steady-state.

A return to baseline contingencies occurred 10 sessions after a steady-state (continued stationary level) had been accomplished with regard to all dependent variables. Subjects then continued to read in the same experimental environment but without benefit of audio feedback. Reversals in subvocalization data were not anticipated at this stage as maintenance of feedback effects were typically independent of the treatment, once learned. However, changes in reading rate and comprehension at this stage were viewed as critical to the efficacy of the treatment. There were 10 postfeedback sessions which measured the subvocal activity as well as reading rate and comprehension.

Two follow-up sessions occurred 1 month after termination of the postfeedback conditions. This follow-up likewise was accomplished without benefit of feedback to the subjects. This phase of the experiment was conducted in order to determine if the various effects of feedback were sustained over time. Measures were again taken on reading rate, comprehension, and laryngeal tension. This final testing served as an index of the potential adequacy of such training and indicated whether such training had any real educational effects.

The effects of EMG feedback on the steady-states of laryngeal activity, reading rate, and comprehension were closely monitored all during the course of this study. The experimenter compared changes in reading rate and comprehension as a function of this biofeedback operation at the various stages previously elaborated on. Dependent variables were analyzed via visual inspection of individual curves. Statistical significance in the changes within each individual's curves, across phases of the experiment, were computed via time-series analysis. Other possible single-subject procedures such as the single-subject analysis of variance models introduced by Shine and Bower (1971) and Gentile, Roden, and Klein (1972) were rejected, as they assume the single-subject to be a response generator whose responses are statistically independent (Glass, 1975, p. 78). But as Glass (1975) points out, operant research generates data in which nonindependence of observations is a highly probable phenomenon. Therefore, time-series analysis was selected as the appropriate data analysis because it is most consistent with operant assumptions.

Time-series involves use of "successive observations throughout a programmed intervention and assesses the characteristics of the change process" (Gottman, McFall, & Barnett, 1969, p. 299). Gottman et al. propose that this design serves several simultaneous advantageous functions. First, it provides a descriptive function because a continuous record of the experimental variables are utilized over the entire time period. Secondly, this design serves as a useful heuristic device because the time-series data provide feedback for generating new hypotheses or as a source for post hoc hypotheses. Thirdly, it can serve as a quasi-experimental design for planned intervention in a total program, without the necessity of a control group. These authors propose that the use of time-series is better at ruling out rival hypotheses than the one-group pretest-posttest design, and more thoroughly enables examination and hypothesis testing about the process of change.

It is only after the correct model for each individual subject is determined via the correlogram that determination of intervention effects can be computed (Glass, 1975, p. 74). Establishing the correct model for each subject's data analysis will be accomplished by three procedures. First, the autoregressive process (p) regresses upon itself one time point so that any time points are predictable from the observation of previous data. This technique is used by Glass (1975) because of his determination that no particular time point is independent of preceding time points. Thus, such an interdependence can be used to forecast future values. This autoregression is a correlation procedure used to determine the degree to which time is a relevant variable or merely a random fluctuation of data points. Second, the order of differencing (d) is a method of determining what differences in the previous time period reoccur. Third, the order of the moving averages (q) addresses itself to data trends which are designated as random shocks which enter the system. This whole procedure ultimately measures a trend over a given time interval and allows for smoothing of the time line.

Glass (1975) points out that about half of the time-series found in practice are adequately described by stationary models. That is, the series tends to maintain in equilibrium around a constant mean level. When this is found to be the case, via examination of the correlogram, p is given an order of 1 in the p, d, q series. When p is 2, the autoregression tends to depart from linearity and assumes some other form such as a quadratic or cubic trend.

When p is 0, a stationary trend does not exist, and d and q must be examined as further indicators of possible trends.

With regard to d, a series is stationary (assumes a limited degree of fluctuation around a particular level) when d is 0. A d of 1 indicates a stationary trend at a particular level for a given time, then drifting to a new level where it again assumes a stationary trend. When d is 2, the change in level of the stationary trend will drift from location to location on the correlogram.

When q is 0, the process is purely autoregressive and no moving average exists. When q is 1, there is a first-order moving average; and when q is 2, there exists a second-order moving average (Glass, 1975).

After model specification was determined, a t-test was used to decide if there were any significant differences in the regression estimates of the trend lines (baseline and experimental) for each individual subject (Glass, 1975, p. 119). Tests of significance for intervention effects were completed for each of the five subjects in the study, and a summary table for each individual subject on the time-series intervention analysis is given. In addition, graphs of each subject's reading proficiency are drawn to show potential changes in comprehension, reading rate, and level of subvocal behavior.

Previous studies in this area have had difficulty in operationalizing the degree of complexity of the written material. For example, Hardyck and Petrinovich (1970) simply selected essays which were rated by a group of eight judges on a 5-point scale of conceptual difficulty and interest level. Though such attempts at defining difficulty are admirable in intent, they are open to serious questions of reliability for individual subjects. For it is obviously the case that difficulty level will fluctuate from reader to reader, depending upon individual differences in reading proficiency.

Difficulty level for individual subjects, in this study, was defined operationally by using a criterion referenced method. The materials selected as subject matter for the research in this paper were analyzed via Bormuth's (1975) Cloze test. The texts consisted of *How to Pass High on the Graduate Record Examination* and *GRE Graduate Record Examination Aptitude Test,* depending on the individual's ability to comprehend at a specified level of the Cloze test. Both of these texts are particularly useful for such research, as they contain a series of objective comprehension questions over the subject matter read. Each of the subjects had the difficulty of these texts determined by criteria reference as specified by the guidelines put forth by Bormuth (1975). Prior to any research on subvocalization, each subject was tested with the Cloze procedure using exerpts from the before mentioned texts. No subject was used in the experiment who did not obtain the approximate level of difficulty recommended by Bormuth.

The Cloze test for determining difficulty of texts is relatively simple and straightforward. An abbreviated version of Bormuth's instructions follows:

1. Select one or more passages to represent the materials being evaluated.

2. Starting with the first word in the passage, count the words, marking every fifth one for deletion.

3. Type a stencil of the passage, but in place of every fifth word indicate a blank by inserting a 15-space underline.

4. Run off copies of this test and administer it without time limits to students. Instruct the students to guess what word was removed to form each blank and to write the word in the blank.

5. Score the responses correct only if they exactly match the words deleted.

One can then compare the percentage of items answered correctly and compare these to any other typical selection of 250 words from another text for comparison. Thus, intra-individual ranges of difficulty for different texts may be criterion referenced for each individual. This was reported in the following experiment.

According to Bormuth (1969):

> The Cloze test taps the comprehension processes at two points by testing how much knowledge was obtained from the text surrounding the blank and how well the information obtained from the text was employed to obtain additional information. Research shows that we cannot distinguish the processes measured by traditional comprehension test questions from those measured by Cloze test items. (p. 364)

The Cloze tests show a reliability correlation between passage rankings of roughly 92% reliability. Traditional tests for comprehension only maintain about 71% reliability. Thus Bormuth states that this test is soundly backed by "empirical evidence" which has been realized as a function of in-depth research.

After Bormuth's specifications, responses are graded correct only when the exact word is filled in. Synonyms are counted as wrong because the scoring of such synonyms has been found to reduce the reliability of the procedure. Minor spelling errors are marked correct if the testee's intention is obvious, but changing of tense is scored as incorrect. Bormuth indicates that the doubling of the raw score gives the percentage correct. That is, a 250-word selection will have 50 answers. This multiplied by 2 gives the percentage correct. Thus, the exact degree of difficulty for the designated reading material was operationally defined in percentage score for each subject prior to feedback operations. Bormuth recommends 44-57% as an appropriate interval indicating that students are having difficulty understanding a given text (Bormuth, 1968). However, for the purposes of this research, any score below 57% was designated as appropriate for undergoing EMG treatment on subvocalization occurring during the reading of "difficult" material.

Results

The data for each of the five subjects on three variables were computed by means of time-series analysis. Baseline was compared to the combined progressions of treatment, posttreatment, and follow-up. A two-tailed t-test was used to determine change in level between baseline and the combined phases that followed. A summary of the time-series intervention effects is illustrated in Table 1. This table displays degrees of freedom, model identification, error variance, significance of intervention effect, change in level, and the degree of significance for each subject with regard to subvocalization, comprehension, and reading rate, in that order.

Graphs depicting the raw data points of each variable are illustrated in Figures 2 through 16 (also see Appendix). These graphs correspond in sequence to variables listed in

Table 1

Summary Table for Time-Series Intervention Analysis

Subject Identification Number	Subvocalization	Comprehension	Reading Rate	df	Identification of Time-Series Model	Error Variance	Significance of Intervention Effect	Change in Level	p
1	X			50	0, 0, 1	2.253	t = -15.56	- 9.29	.001
2	X			50	0, 0, 1	4.448	t = -17.41	-14.25	.001
3	X			50	1, 0, 0	5.125	t = -16.16	-22.44	.001
4	X			50	0, 0, 1	24.284	t = -42.79	-67.23	.001
5	X			50	0, 0, 1	20.567	t = -21.16	-36.32	.001
1		X		50	0, 0, 1	235.898	t = .06	0.27	--
2		X		50	0, 0, 1	286.505	t = .77	3.95	--
3		X		50	0, 1, 1	262.881	t = -3.32	-47.81	.001
4		X		50	0, 1, 1	208.386	t = -4.29	-49.53	.001
5		X		50	0, 0, 1	349.589	t = .45	2.25	--
1			X	50	0, 0, 1	306.214	t = 10.58	63.48	.001
*2			X	50	0, 0, 1	857.069	t = 5.91	66.79	.001
3			X	50	0, 0, 1	347.001	t = 6.11	41.97	.001
4			X	50	0, 0, 1	173.314	t = 6.63	31.74	.001
5			X	50	1, 0, 0	340.261	t = 2.08	23.50	.01

*Reading rate of S2 required post hoc procedure of baseline extension to acquire significance.

Table 1. All variables permitted 50 degrees of freedom. The predominant model identified throughout the study was a first-order moving-average model. This is depicted as (0, 0, 1), with specific reference to the order of the auto-regression, the order of difference, and the order of the moving average, respectively.

Subvocalization

Using the chart recorder and digital readout analog, subvocalization was calculated as the average number of voltage spikes above rest threshold, rounded to the nearest whole number, per 10-second interval. This average necessarily excluded intervals with swallow or head-turning artifact. Subvocalization existed in varying degrees of magnitude in each of the five subjects. Baselines indicated wide differences between subjects ranging from an average high of 75 subvocal spikes above rest threshold during one session of subject 4, to a low baseline session of 6 on subject 1. Likewise, baseline levels indicated considerable fluctuation within subjects from session to session. However, reasonable stabilization was obtained after 20 sessions of baseline.

All subjects were capable of eliminating all detectable subvocalization within 13 sessions of treatment. But again there was considerable variability between subjects with regard to the speed with which this subvocal tendency was reduced. Further, individual subvocalization graphs do not indicate any consistent relationship between the magnitude of a given subject's baseline subvocalization and his propensity toward reduction of that tendency.

All subjects maintained complete elimination of subvocalization after the tendency was inhibited by way of practice with feedback. Likewise, the subvocal behavior was not shown in any of the subjects in any of the 10 posttreatment sessions which followed the audio-feedback sessions or in either of the two follow-up sessions which occurred approximately 1 month after the posttreatment sessions (see Figures 2 through 6).

It is important to note that since these subjects had eliminated subvocalization and thus the audio-feedback which accompanies it before half of the treatments were over, these remaining treatment sessions were similar to the posttreatment and follow-up in that little feedback was heard by the subjects during this time. But it should be noted that some subjects were occasionally exposed to audio-feedback during the second half of treatment as a function of laryngeal artifact produced by head movement and swallowing. Such artifact may account for the delayed increases in reading rates which occurred in subjects 1 and 3 during the posttreatment and follow-up phases. That is, during

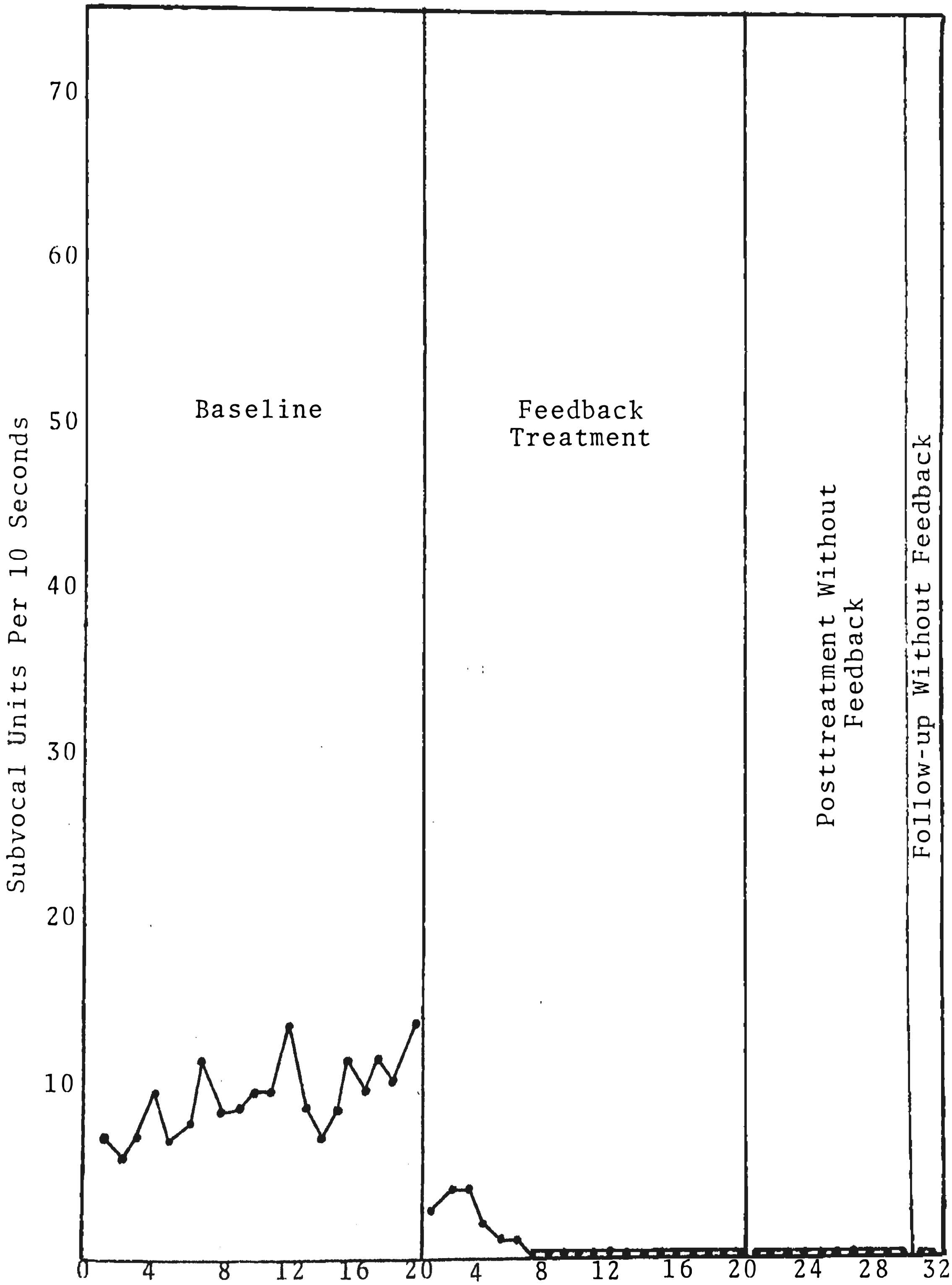

Figure 2. Data sessions, subject 1.

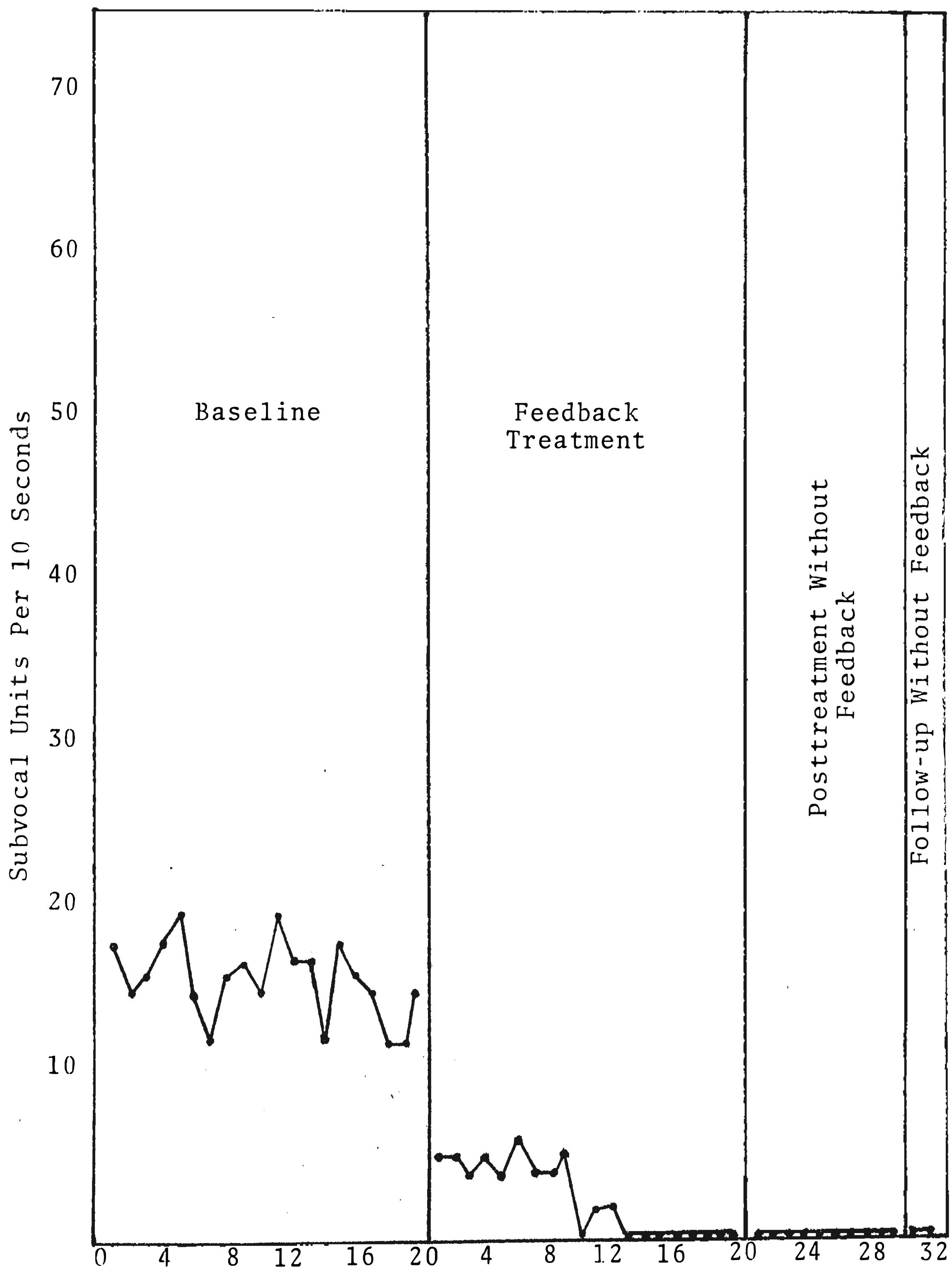

Figure 3. Data sessions, subject 2.

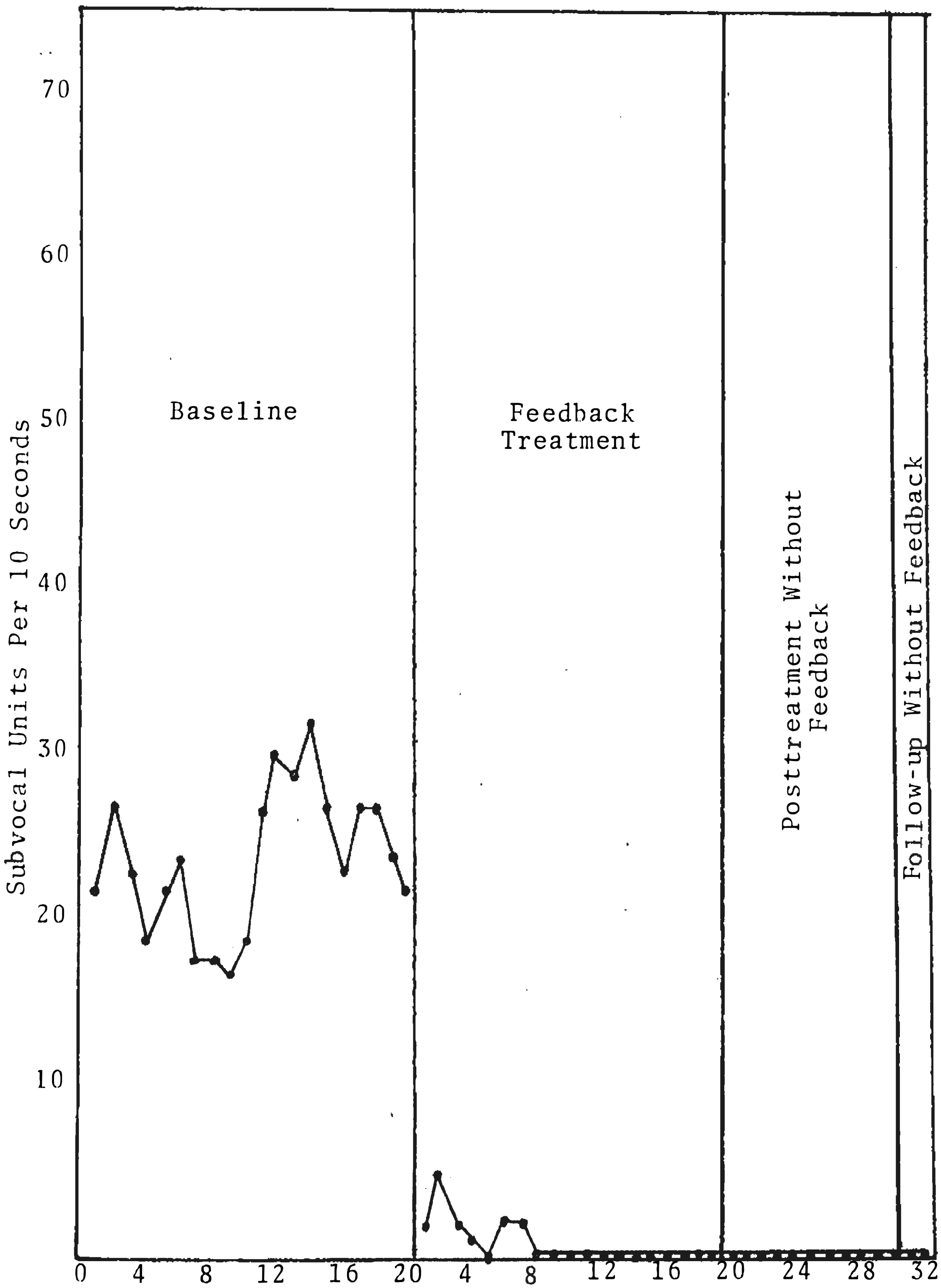

Figure 4. Data sessions, subject 3.

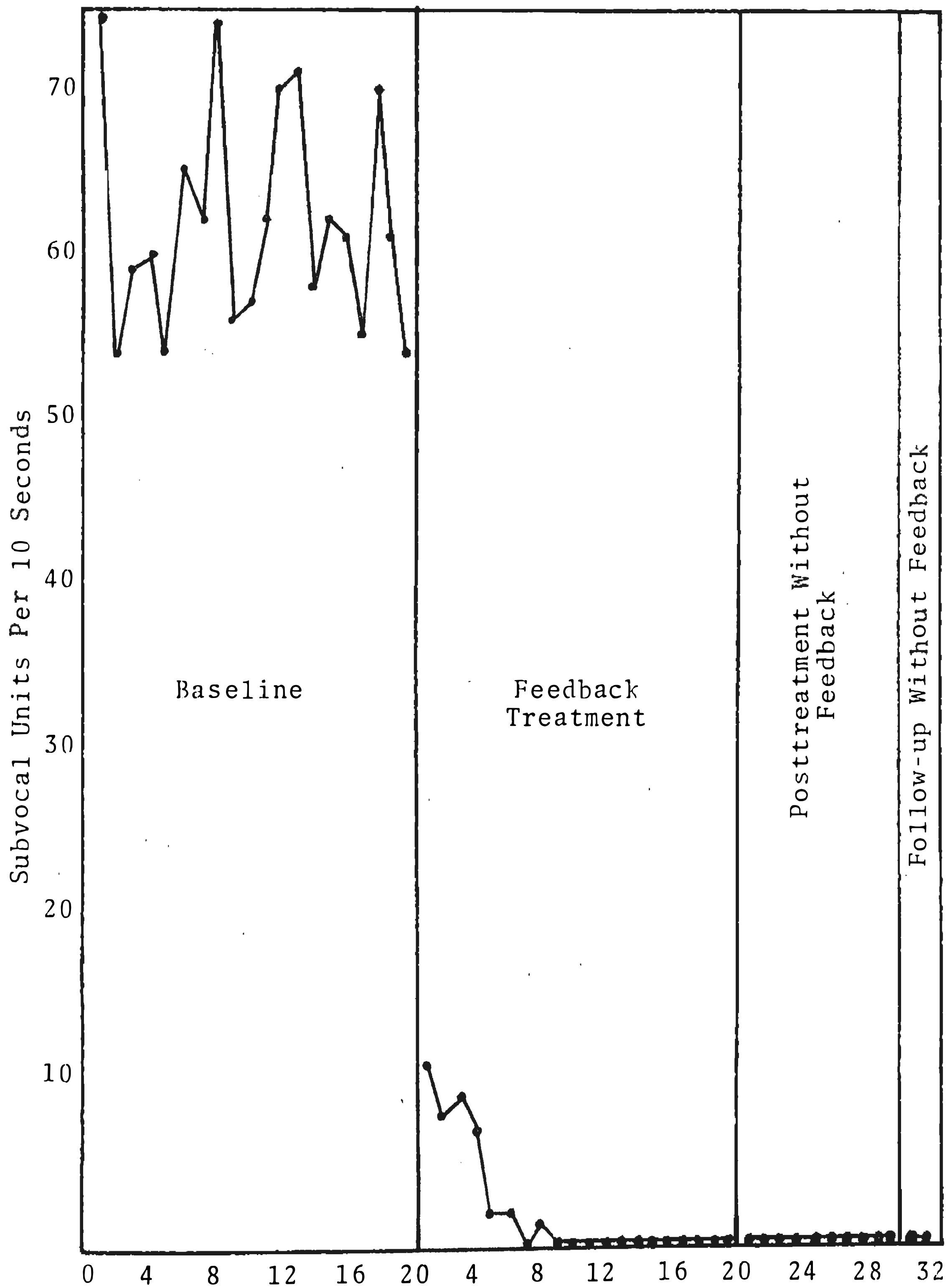

Figure 5. Data sessions, subject 4.

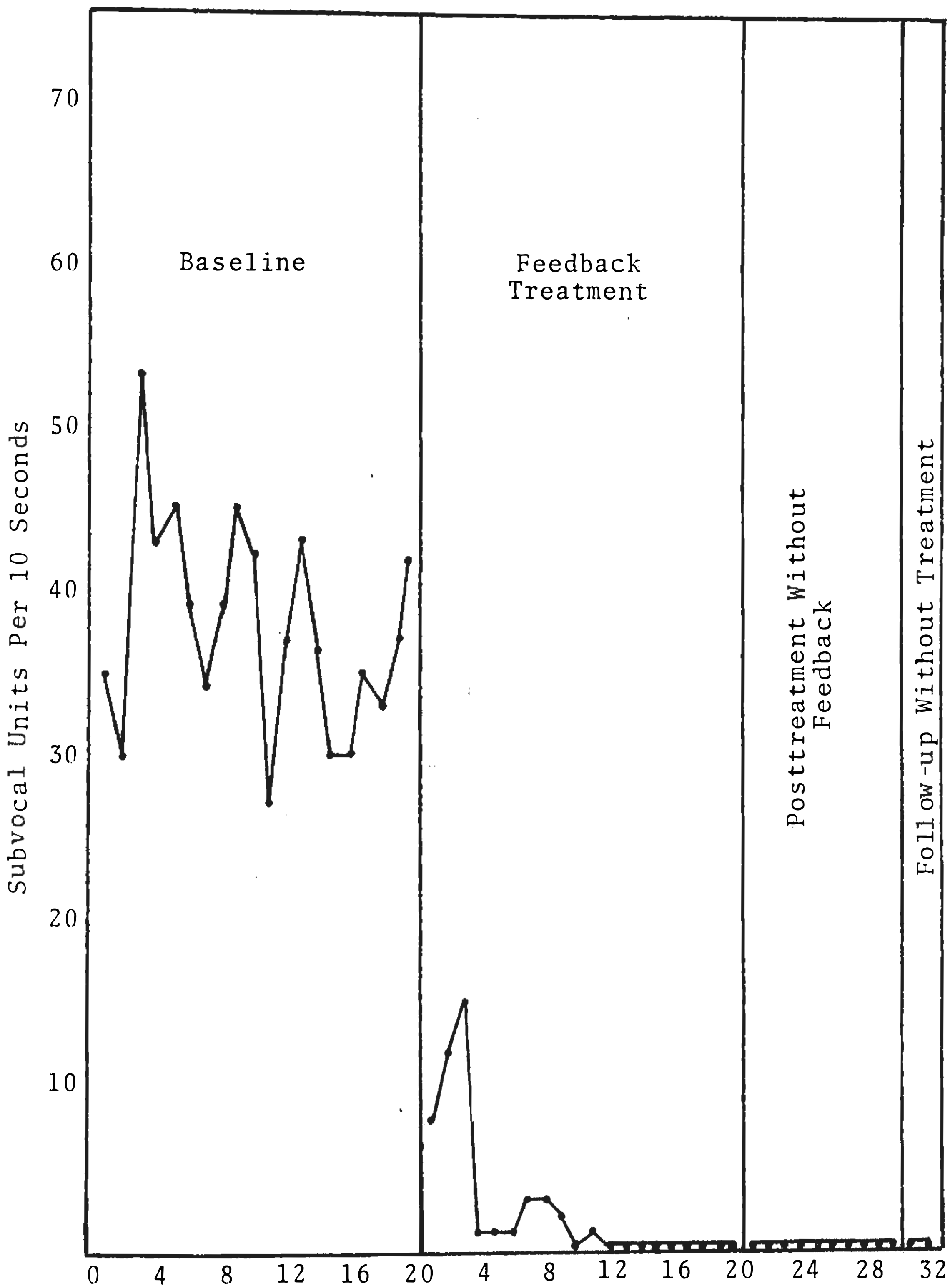

Figure 6. Data sessions, subject 5.

these last two phases without feedback, these subjects were not even occasionally distracted by such artifact produced by head movement and swallowing. Thus, their concentration might have been enhanced when such occasional distractions were eliminated.

The first subject's subvocalization data were identified as a first-order moving-averages model depicted as (0, 0, 1). The minimum error variance was 2.253. The t-statistic produced a value of -15.56 showing a -9.29 level of change. This value was highly significant with a _p_ of less than .001. Figure 2 illustrates a baseline steady-state fluctuating around 10 subvocal spikes above rest threshold per 10 seconds. Subvocal reading was reduced drastically in the first six sessions of treatment and remained at zero throughout the rest of the treatment, post-treatment, and follow-up phases.

Subject 2's behavior also fit a first-order moving-averages model (0, 0, 1) on the subvocalization variable. The minimum error variance was 4.448, showing a change in level of -14.25 and a t of -17.41. This reduction in subvocal behavior was again highly significant with a _p_ of less than .001. Figure 3 displays a stable baseline around 16 subvocal spikes above rest threshold. This level quickly dropped about 75% during the first nine treatment sessions and finally truncates to zero by session 13. There was no sign of any subvocal behavior throughout the rest of the data sessions.

Subject 3 was identified as a first-order autoregressive model (1, 0, 0). Error variance was calculated at 5.125 with a change in level at intervention of -22.44. The t-test was highly significant with a p of less than .001. The raw data points described in Figure 4 show a somewhat stable baseline approximating 24 subvocal spikes above rest threshold per 10-second interval. This subject almost completely eliminated the subvocal tendency on the first treatment session. After slight facilation over seven sessions, subvocalization truncates for the remainder of the data.

Subject 4 resumed a first-order moving-averages model, (0, 0, 1), with an error variance of 24.284. The level of change at intervention dropped to -67.23, producing an extreme t-test outcome of -42.79. This was highly significant and p was less than .001. Figure 5 shows the immediate and almost complete cessation of laryngeal activity upon introduction of feedback while reading. The data dropped to zero by the ninth session and remained at rest level through the course of the experiment.

The fifth and final subject also was identified as a first-order moving-averages model (0, 0, 1). Error variance was calculated at 20.567 and the level of change decelerated

-36.32. The t was -21.16 which was highly significant with a p less than .001. Raw subvocalization data depicted on Figure 6 show wide variations within the steady-state on baseline. Again the subvocal spiking dropped at feedback intervention and reached an extremely low level by the fourth session. By the 12th session spiking dropped to prereading rest levels and remained at that level throughout the rest of the treatment, posttreatment, and follow-up phases.

It is quite clear from both the time-series intervention analysis and the graphs of raw data that subvocalization can be and was quickly eliminated using electromyographic feedback. Further, it is apparent that there existed no tendency, in any of the five subjects, to resume subvocalization after treatment or even at 1-month follow-ups. The effects of this change in reading style is quite vividly displayed in the analysis of the two remaining variables, comprehension and reading speed.

Comprehension

Comprehension was measured using two methods. The Cloze test, as described previously, proved to be a valuable index of intersubject variability with regard to predicting level of difficulty of the reading material. Secondly, the objective tests given at the end of each reading session proved a reliable index of each subject's relatively consistent comprehension level through the course of the baseline, treatment, posttreatment, and follow-up phases.

The Cloze test predicted rather accurately those subjects who would find the reading material most strenuous. Subject 2 scored the highest at 42, followed by Subject 1 with a score of 33. Subjects 5, 4, and 3 scored within a close range of one another obtaining low scores of 26, 22, and 20, respectively. This pattern corresponds rather closely to the percentage of objective questions answered correctly throughout the experiment by each of these subjects. No subject ever approached the cutoff point of 57, above which was designated as material too easy for this study.

Contrary to expectation, only three of the five subjects displayed any conspicuous drop in comprehension level upon reduction of subvocalization via feedback, and only two subjects showed any statistically significant drop in comprehension. It is important to point out that this drop in comprehension, although significant, was only temporary. In all three subjects who displayed comprehension losses, acceleration back to baseline level occurred within 10 sessions after treatment. Baseline levels of comprehension were maintained throughout the duration of treatment, posttreatment, and follow-up. It is clear that eliminating subvocal behavior did not improve reading comprehension, but it is equally clear from comprehension graphs that practice in reading difficult material without subvocalizing compensated for temporary losses in understanding. Thus, there does not appear to be any justification for the notion that elimination of subvocalization decreases comprehension of difficult material. However, this fact only becomes clear when subjects are given consistent and continued practice in reading such difficult material while not subvocalizing during that process (see Figures 7-11).

The comprehension data of subject 1 assumed a first-order moving-averages model. Error variance was computed at 235.898. The change in level was only .27 and the t-test was not significant with a value of .06. Raw data on Figure 7 for this subject show no tendency for reduction or gain in comprehension as a function of reduced subvocalization via feedback.

Subject 2 was also identified as a first-order moving-averages model (0, 0, 1) on comprehension. The error variance for this subject was 286.505 and the change in level was only 3.95. This resulted in nonsignificant t-test of .77. Figure 8 illustrates a steady-state pattern throughout the course of the study, independent of the various phases. This subject obtained the highest consistent comprehension scores and was evidently not affected by treatment. It is

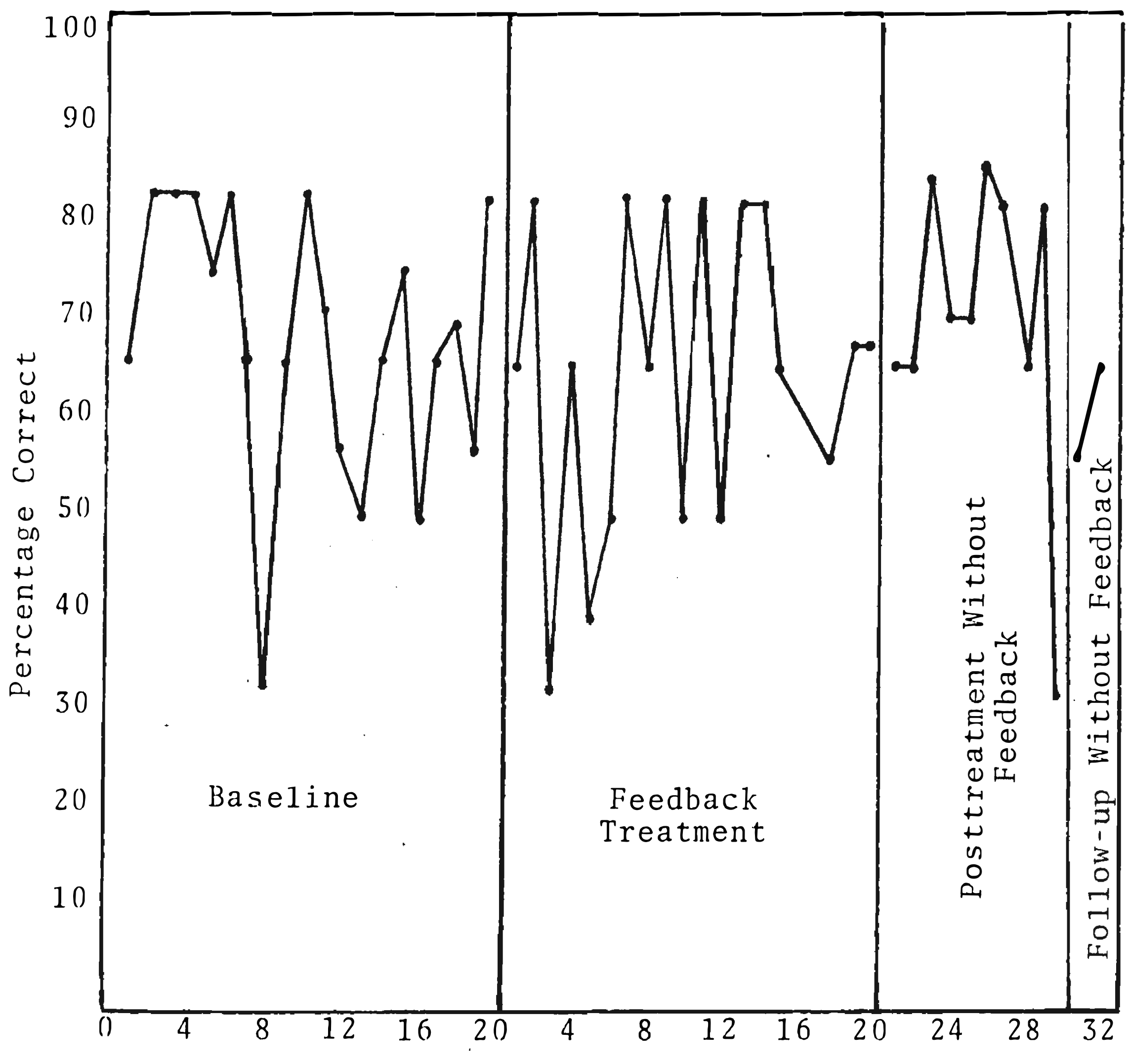

Figure 7. Data sessions, subject 1.

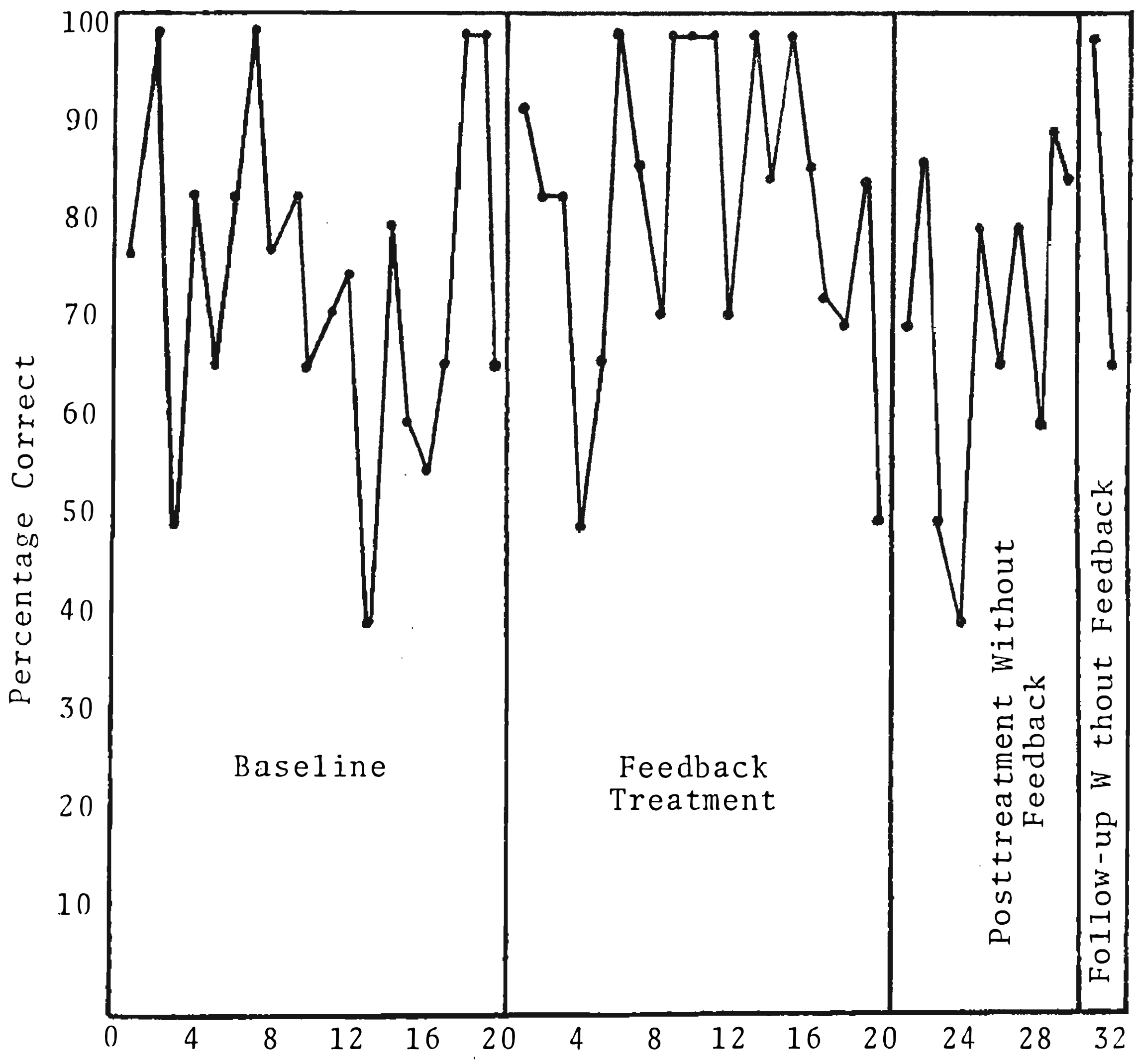

Figure 8. Data sessions, subject 2.

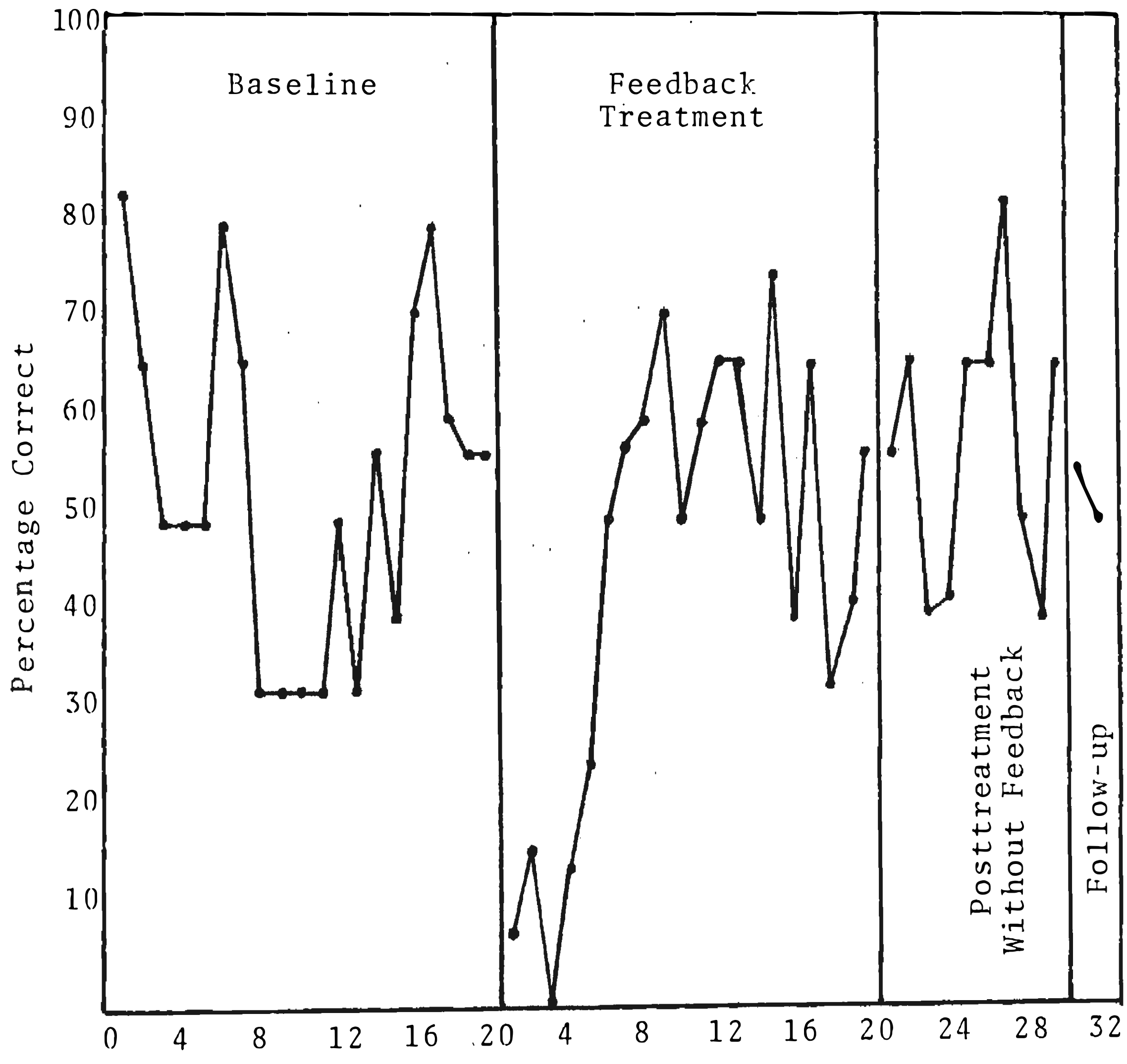

Figure 9. Data sessions, subject 3.

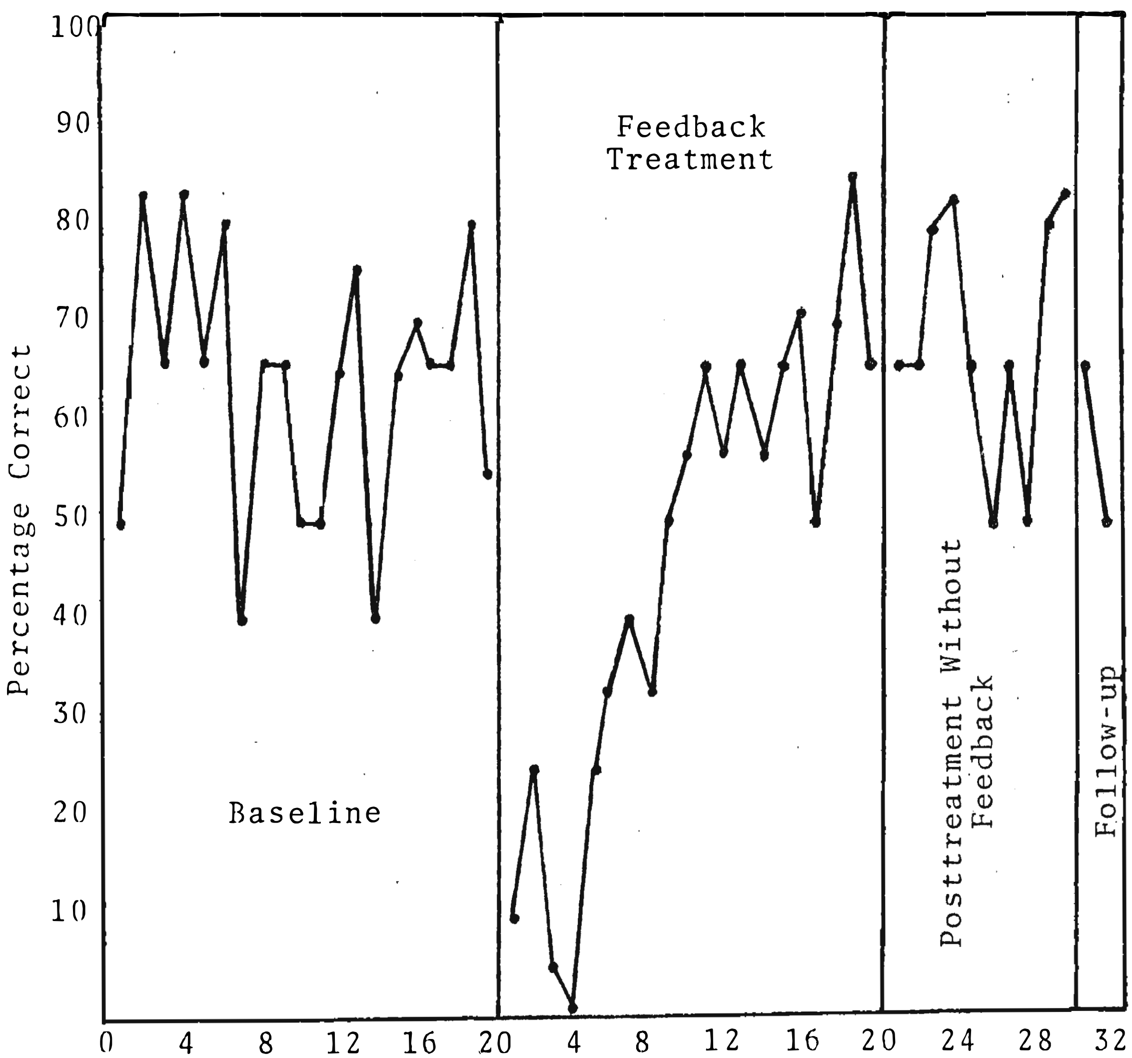

Figure 10. Data sessions, subject 4.

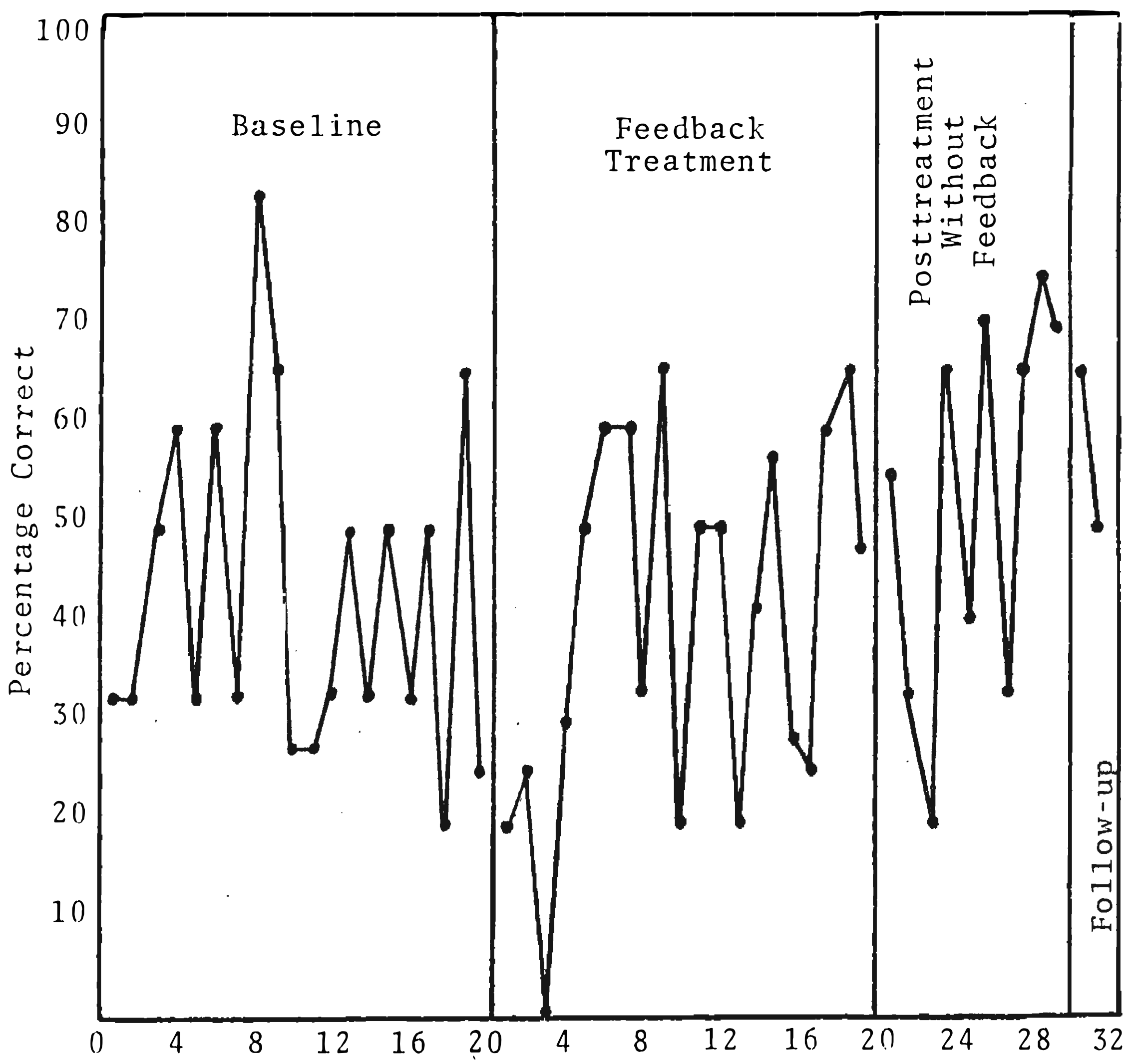

Figure 11. Data sessions, subject 5.

important to note that this subject similarly obtained the highest Cloze score, 42.

Subject 3's data were identified as an integrated moving-averages model (0, 1, 1). Integration in this model refers to the conspicuous nonstationarity in level which occurred just after treatment was introduced. Error variance was computed at 262.881 and change in level was designated as -47.81. This produced a highly significant t-test at -3.32; p was less than .001.

Although this change in level is statistically different from zero at the point of intervention, it is important to note that this effect is only temporary and that the data for this subject's comprehension, illustrated on Figure 9, show quite clearly that baseline comprehension is resumed completely by the eighth treatment session. The data maintained a steady-state throughout the duration of study.

The fourth subject was similarly identified as an integrated moving-averages model (0, 1, 1). Nonstationarity is again conspicuous in raw data, Figure 10. Error variance was documented at 208.386 with a -49.53 change in level at intervention. The t-test was significant at -4.29 and p was less than .001. Once more it is important to specify the ephemeral nature of this nonstationarity. This becomes clear as the data resume a baseline level after nine treatment sessions and show no tendency toward deceleration after that point.

The fifth subject's data assumed a first-order moving-averages model (0, 0, 1) for the data analysis. Error variance was computed at 349.589. A slight change in level was noted at 2.25. This was not statistically significant as the t-test was only .45. Raw data on Figure 10 show this subject to have obtained a slight, temporary drop in comprehension on the third treatment session. The remainder of data appear to maintain a low but constant level.

Reading Rate

All five subjects displayed conspicuous increases in reading rate during the treatment phase of the experiment. These increases were maintained throughout the course of the posttreatment phase in which no opportunity for feedback existed and during the follow-up testing without feedback 1 month after the termination of the posttreatment phase. But only one subject made this transition to faster reading immediately after feedback training. The remaining four subjects displayed a delayed treatment effect. This delayed treatment effect in reading speed of difficult material is probably due to a number of factors. Most conspicuously, the feedback signals continued to operate during the sessions at the beginning of treatment. This erratic audio-feedback indicated low levels of subvocalization and may have distracted many of the subjects, thus lowering this reading rate and in some cases possibly contributing to temporary decreases in comprehension (see Figures 12-16).

Since obtainment of significant differences in time-series analysis is most critical at the point just after intervention, a delayed treatment effect reduces power. This effect was most noticeable in subject 2 where a post hoc procedure of extending the baseline 9 points was necessary in order to display a significant treatment effect. Such a procedure would have undoubtedly increased the level of significance of the t-test on the other four subjects but was unnecessary since these subjects obtained high significance levels without invoking this post hoc procedure (Glass, 1978).

The reading rate data of subject 1 were identified as a first-order moving-averages model with an error variance of 306.214. The level of significance necessary to reject the null hypothesis for 50 degrees of freedom was 3.698. Thus, total change in the level of reading rate was exceptionally high at 63.48. The t-test was 10.58 and thus was highly significant at .001. Analysis of Figure 12 reveals that this is the only subject which did not reveal a delayed treatment effect. Change in reading rate is immediate and durable throughout the various phases. This immediate transition to a high rate accounts for the high level of

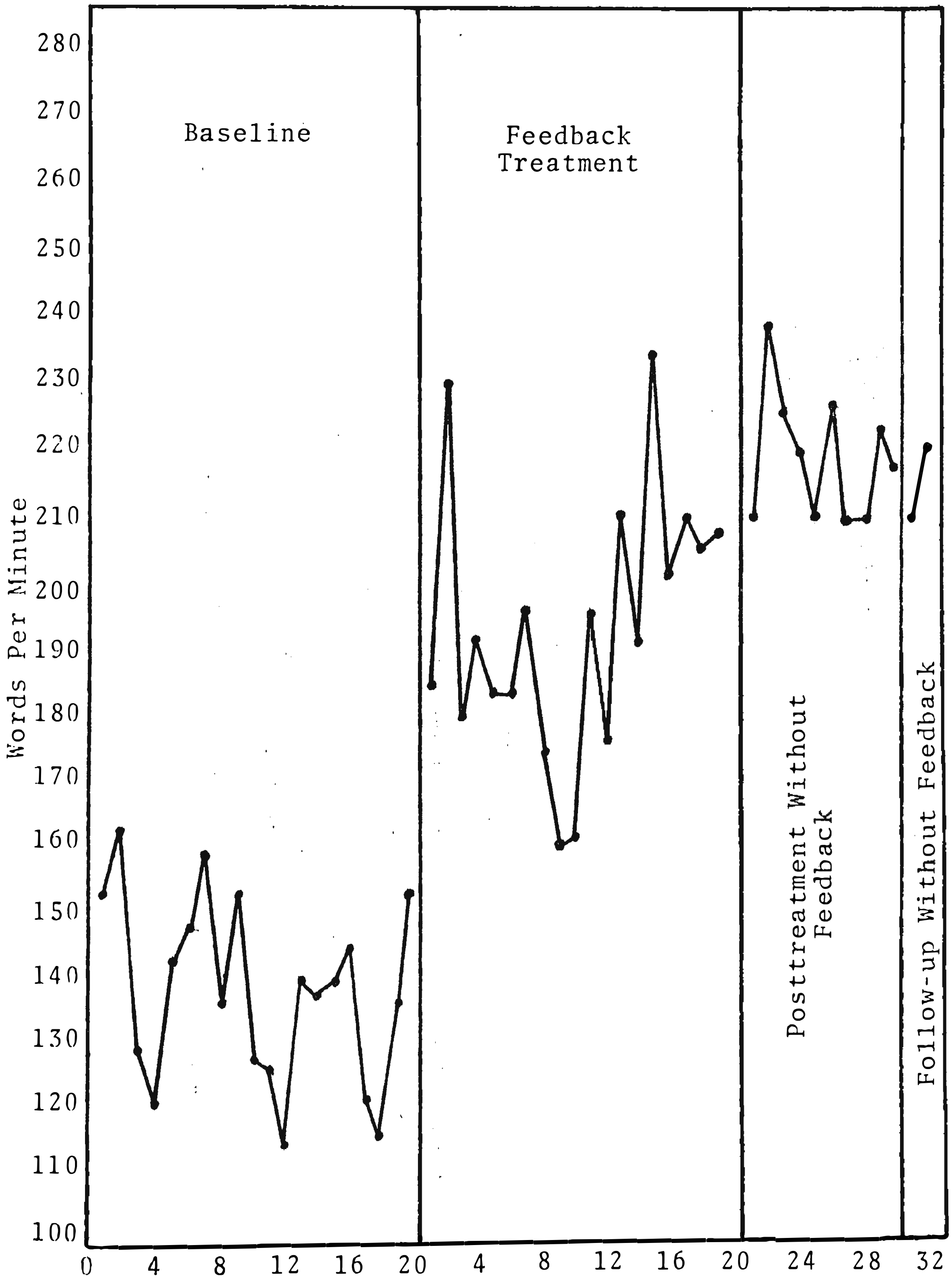

Figure 12. Data sessions, subject 1.

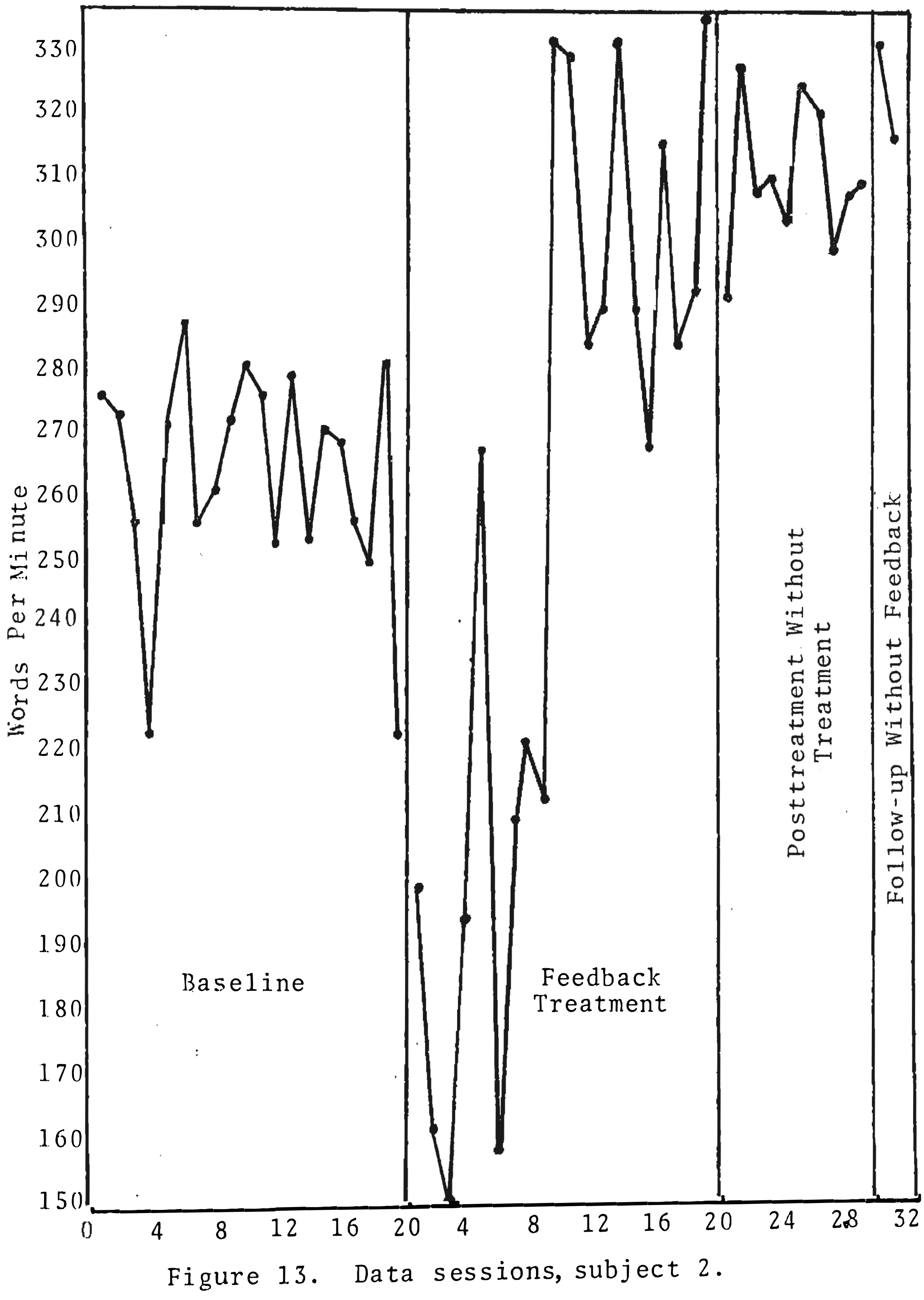

Figure 13. Data sessions, subject 2.

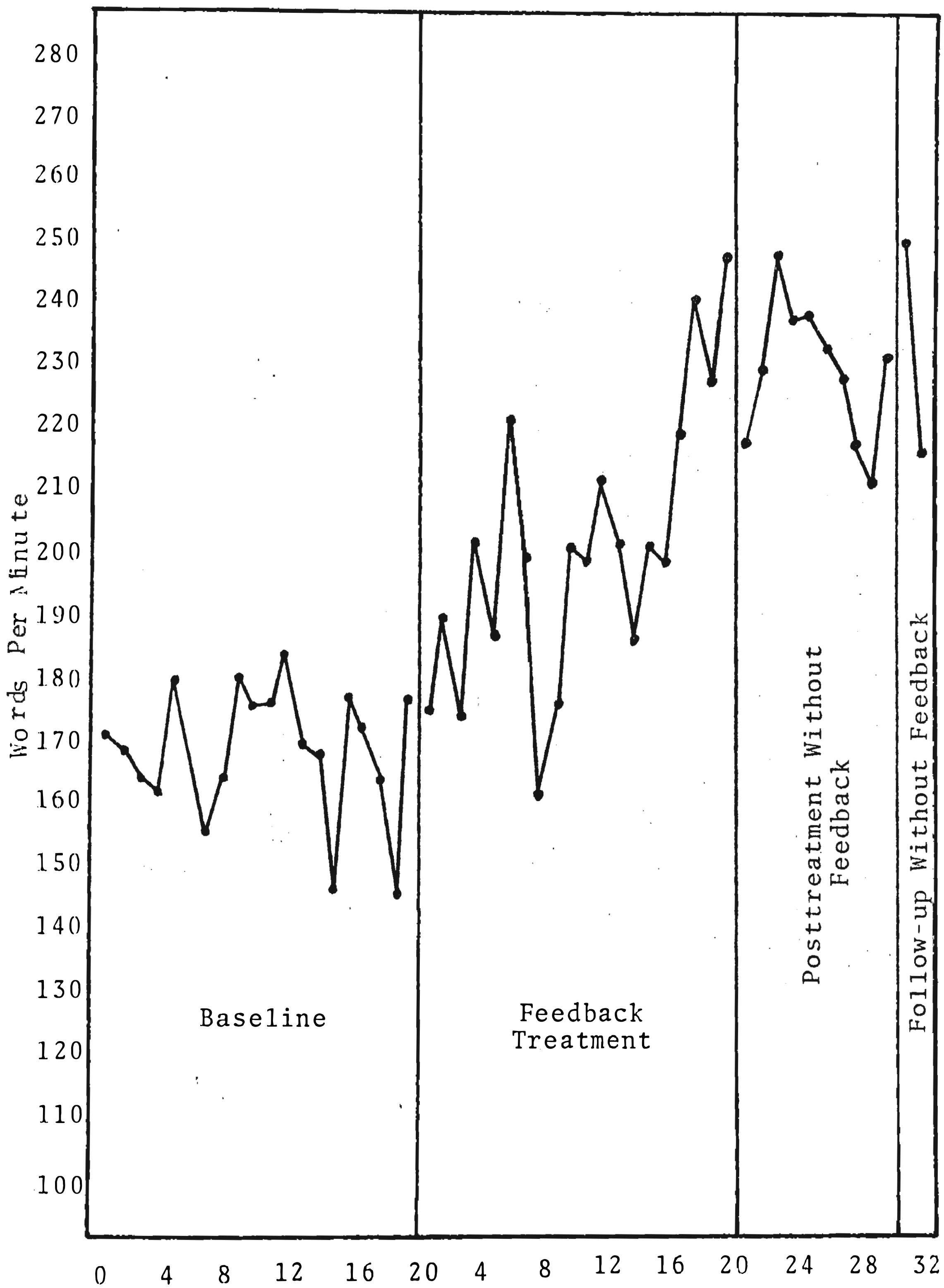

Figure 14. Data sessions, subject 3.

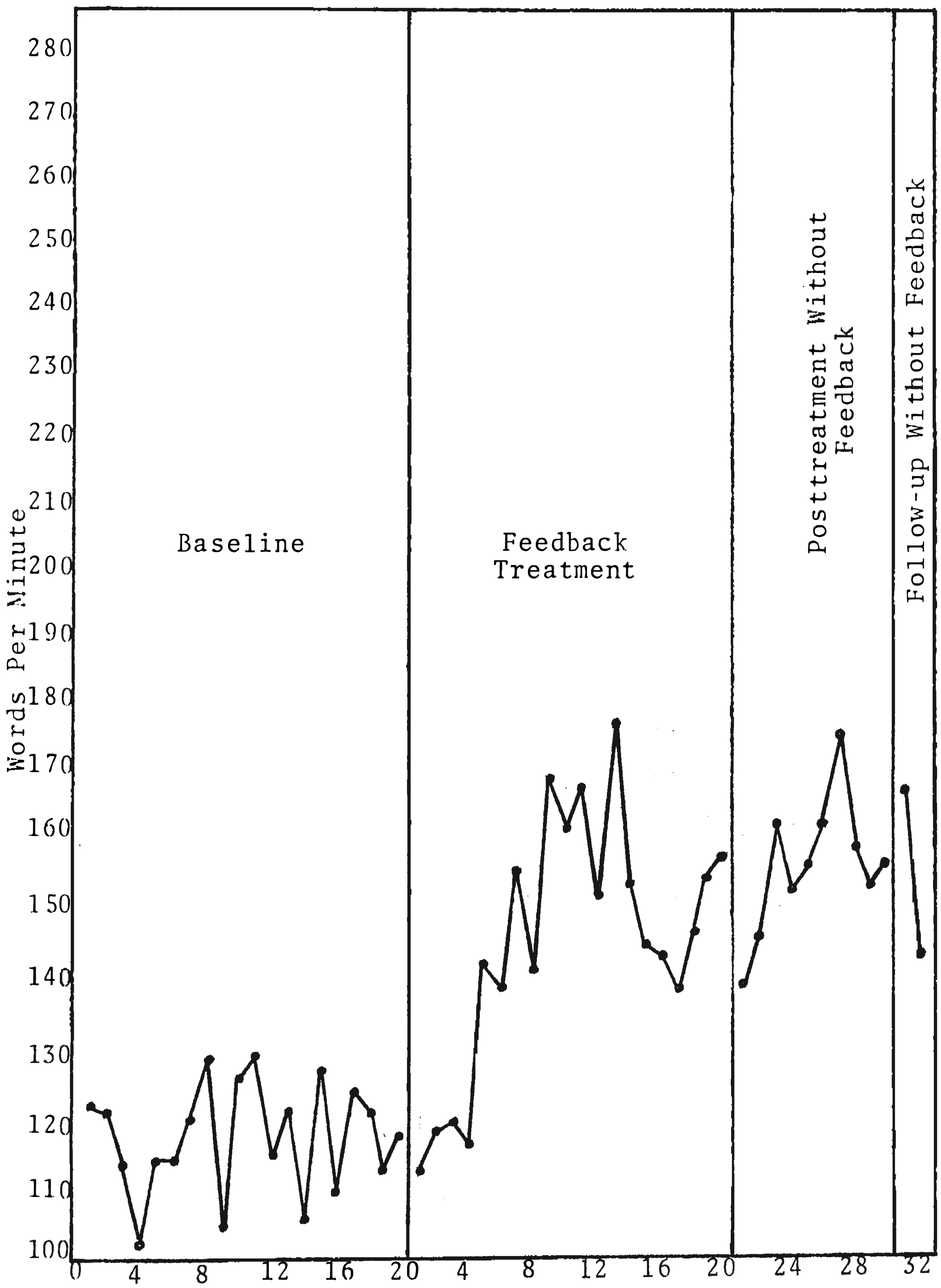

Figure 15. Data sessions, subject 4.

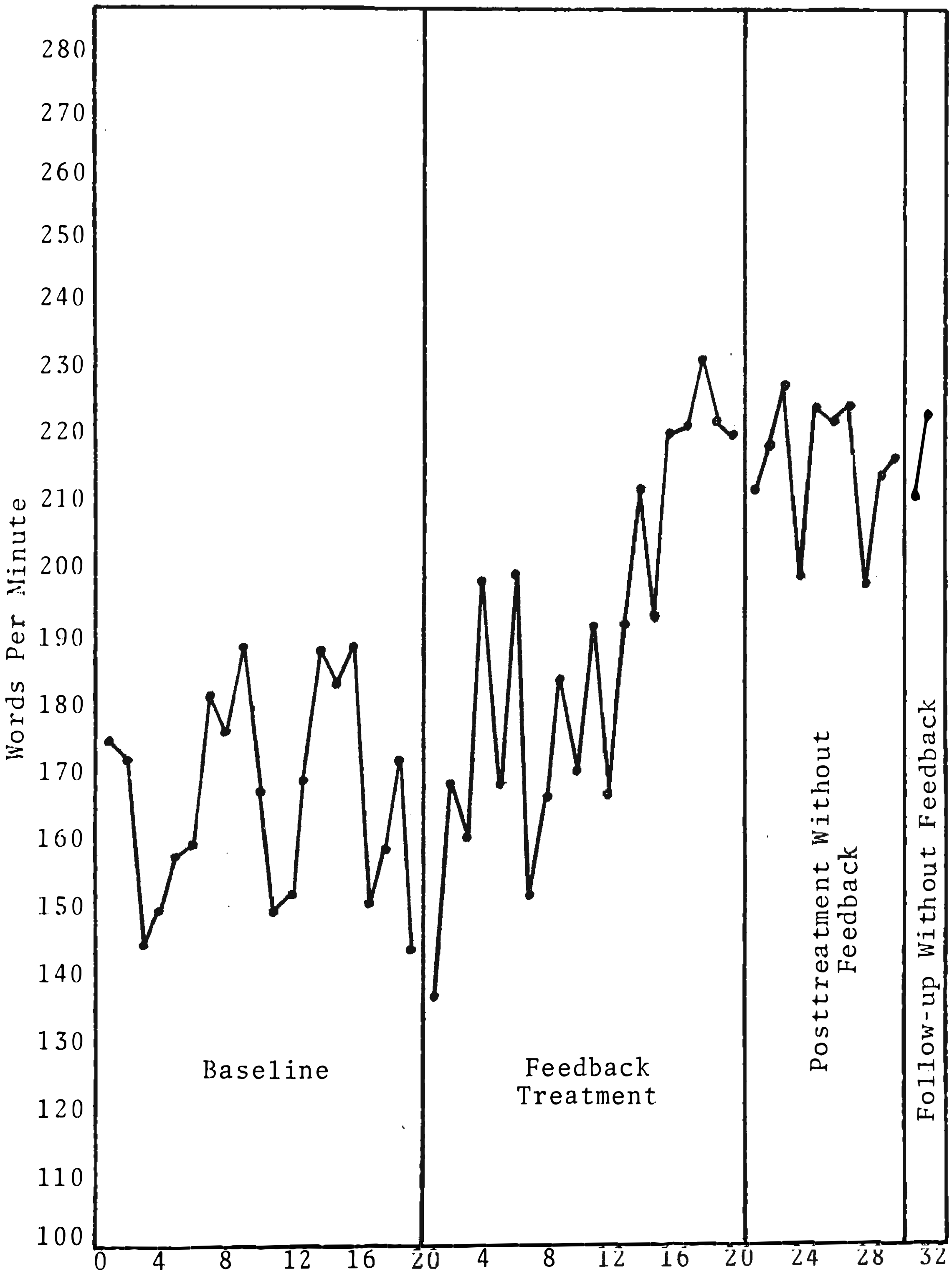

Figure 16. Data sessions, subject 5.

significance without loss of power. Analysis of the last five reading rates on baseline versus the last five combined posttreatment and follow-up phases reveals an average increase from 134.8 words per minute to 217.2 words per minute, a 37.94% increase over baseline data.

Subject 2 was also defined as a first-order moving-averages model (0, 0, 1). Error variance was 857.069. Total change in level was 66.79 with a t-test of 5.91; p was highly significant at less than .001. Figure 13 reveals an exceptionally elongated delayed treatment effect. It will be recalled this subject's tendency toward subvocalization was likewise elongated after intervention (Figure 3). It is highly probable that erratic feedback produced during this first part of treatment distracted the subject substantially, thus slowing the reading rate. Regardless of the cause of this delay, the results produced a nonsignificant t-test on the first run of the data. A post hoc procedure of extending the baseline from 20 to 29 compensated for the delayed treatment effect by incorporating this delay within the baseline phase. This allowed the greatest change in level to occur at the point of intervention. Such a post hoc technique is both permissible and advisable when such delayed treatment effects decrease power substantially (Glass, 1975). After the eighth treatment, the subject's data maintain a constant high level throughout the remainder of the study. Analysis of the last five reading rates at preintervention and postintervention displays an average increase from 256.2 words per minute to 312.63 words per minute. This represents a 18.06% increase over baseline data.

Subject 3 was identified as a first-order moving-averages (0, 0, 1) model. Error variance for this subject's reading speed was 347.001. The data changed in level 41.97, producing a t-test of 6.11. This p was highly significant at .001. Figure 14 indicates a slight delayed treatment effect in this subject. The reading speed starts to increase above baseline almost immediately and gradually accelerates until about the 17th treatment session. At this point, the data remain at a constant level throughout the rest of the various phases. The last five reading rates on preintervention and postintervention display a change from an average 172.6 words per minute to 227.6 words per minute. This produces a 24.17% increase over baseline data.

Again the fourth subject's data were identified as a first-order moving-averages model. Error variance was computed at 173.314. The total data changed in level by 31.74. The t-test was 6.63, producing a highly significant p less than .001. Figure 15 evidences a slight delayed treatment effect as the subject builds reading rate over the first eight treatment sessions. The remaining sessions show some facilation but approximate higher levels than baseline or the initial treatment sessions. The last five sessions of preintervention and postintervention show an increase from 117.4 words per minute to 164 words per minute. This represents a 28.42% increase over baseline data for the last 5 data points.

The fifth subject was identified as a first-order autoregressive model (1, 0, 0). Error variance was calculated at 340.261. A change in level of 23.50 produced a t-test value of 2.08; p was significant at less than .01. Figure 16 displays a reading rate which accelerates gradually after intervention and reaches a constant level at about the 16th session of intervention. The data maintain a constant level for the duration of the experimental phases. The last 5 data points of preintervention and postintervention indicate an average acceleration from 164.2 words per minute to 217.4 words per minute. This indicates 24.48% increase in reading speed after intervention.

Discussion

The results seem to indicate that elimination of subvocalization increases the reading speed of difficult material. Comprehension does quite conspicuously suffer in the initial treatment sessions for some subjects, but comprehension can be built back up to baseline levels if the subject is given further practice with the same type of material while being continually monitored for any subvocal tendencies. These two findings substantiate the notion that such electromyographic feedback from the laryngeal apparatus can facilitate reading speed at all levels of difficulty without loss of comprehension. Hardyck and Petrinovich (1970) found that feedback from the larynx while reading difficult material reduced comprehension level. In the study reported here, three of the five subjects showed that same tendency for a given period of time. Extending the number of sessions, as in the present study, allowed subjects to regain comprehension losses. The need for practice with difficult material, while being monitored with feedback over an extended time period, cannot be overemphasized. Apparently, this variable had not been given adequate consideration in previous research in this area. While it is still probably true that proprioception, via the larynx, can serve as a stimulus support for reading comprehension, it seems apparent, from comprehension graphs, that subjects can learn to read adequately at various ranges of difficulty, independent of such proprioception. In this study, even those subjects who, according to the results of the Cloze test, found the material most difficult were able to regain baseline levels of comprehension with extended periods of practice.

But the results failed to confirm any simple relationship between subvocalization, comprehension, and reading speed on difficult material. Contrary to experimenter expectations, those subvocalizing subjects who performed at particularly slow reading rate during baseline did not improve as a function of treatment to even baseline reading rates of other subvocalizing subjects. One subject was capable of reading approximately 270 words per minute on baseline while subvocalizing. This is a faster rate than posttreatment levels achieved by some subjects who had their subvocal behavior eliminated as a function of biofeedback treatment. Thus, while it is true that these latter subjects did increase their rates over baseline, it is evident that subvocalization is not the only variable contributing to reduction in reading rate.

The Cloze test, indicating level of text difficulty for each individual subject, gives one possible explanation for this phenomenon. Subject 2, who had the highest baseline and posttreatment reading rate, also had the highest Cloze test score. A similar pattern existed for the remaining subjects. Those with low Cloze test scores had slower reading rates. It is highly probable that the actual difficulty of the text for each individual subject contributed to the rate with which that subject could process such reading stimuli, in conjunction with the existence or nonexistence of subvocal behavior.

As Tinker (1962) points out, rapid recognition and understanding occurs only when the text contains words that have been encountered in previous readings. Unfamiliar words are recognized less quickly and only after a slight delay. Such a factor along with any existing subvocal behavior also plays a major role in determining reading rate. It would therefore seem unadvisable to promote reading methods which whip up reading speed but do not allow adequate time for word recognition.

The above issue leads to some further ramifications regarding reading rate. Perhaps the only limited increases in reading speed that have been accomplished by eliminating subvocalization are related to some ambiguities regarding the definition of subvocalization. The behavior eliminated was muscle movement in the larynx and tongue concomitant with reading. Such activity was operationally defined as subvocalization. No other forms of covert verbalization are capable of being monitored or eliminated via electromyographic feedback. Thus the inner process of imagining word sounds while reading was probably still maintained by the subjects in the experiment, but without the peripheral concomitant of subvocalization. While elimination of the actual muscle activity in the tongue and larynx does apparently produce small increases in reading speed, this cannot be compared with eliminating all covert verbalization while reading. Nevertheless, it has often been understood by various researchers in this field (Sokolov, 1972; Reed, 1916) that subvocalization includes both peripheral movement and imagination of word sounds and that these are linked together. Such is not the case, for imagination of word sounds can and does exist independent of any peripheral muscle movement in the throat. The following illustrates how such imagination of word sounds can be eliminated. Typically, reading speeds can be increased dramatically via speed reading courses that require the subject to not only stop peripheral activity while reading, but also require the complete cessation of all imagination of word sounds. This may be accomplished in a number of ways. Subjects may be told to covertly repeat certain digits over and over as they read their texts. Other popular methods require skimming words, backward reading, and reading more than one line at a time. Such courses frequently demonstrate astounding increases in reading speed and even claim increased comprehension. But the claims of increased or even maintained comprehension with such techniques is open to serious question. If such courses actually improved or could even stabilize comprehension at pre-speed-reading levels while producing such drastic increases, they would obviously be of great benefit to students taking such tests as the SAT or GRE. But as Whimbey (1975) points out, no speed reading course makes this claim, probably because they realize that they would quickly be accused of false advertising.

Speed reading, as popularly taught, may well double or even triple the rate at which the individual is exposed to the written word, but again as Whimbey (1975) suggests, "speed reading cannot possibly impart comprehension of new and complex ideas, but can only provide a superficial acquaintance with topics" (p. 97). Thus, there is a great deal of difference between the individual who reads without making minute oral approximations with his tongue as he reads and the person who merely looks at the written words without even imagining the word sounds. While both individuals read faster than they would using their vocal apparatus in the reading process, the former will read only slightly faster than he would if he used his tongue and larynx as he read. The latter may read three times as quickly. However, the former may be taught to maintain high levels of comprehension, while it is extremely doubtful that the latter acquires anything more than superficial acquaintance with the written word.

The emphasis in this experiment has been to demonstrate the individual's ability to acquire an accelerated reading skill with difficult material while maintaining comprehension. Increases of 50 to 80 words per minute have permitted subjects to significantly increase their initial reading rate, while allowing adequate time for information processing.

The reading rate acquisition curves indicate either a continual acceleration toward an apparent asymptote or a delayed treatment effect which temporarily decreased reading speed but eventually surpassed previous levels. The question arises as to whether this 50 to 80 word-per-minute increase with maintained comprehension is the ultimate potential gain using this method. It seems apparent that this instrument has permitted an optimum signal to noise ratio and that subjects have been given adequate time to become acclimated to benefits provided from such sophisticated equipment. Therefore, it seems highly probable that at least the subjects used in this experiment have obtained the maximum potential benefit capable of being derived from such electromyographic feedback with regard to increased reading speed and maintained comprehension of difficult material.

APPENDIX

Raw Data--Subvocal Units *per* 10 Seconds

	Subject 1	Subject 2	Subject 3	Subject 4	Subject 5
			Baseline		
1	7	18	22	75	35
2	6	15	27	54	30
3	7	16	23	59	53
4	10	18	19	60	43
5	7	20	22	54	45
6	8	15	24	65	39
7	12	12	18	62	34
8	9	16	18	74	39
9	9	17	17	56	45
10	10	15	19	57	42
11	10	20	27	62	27
12	14	17	30	70	37
13	9	17	29	71	43
14	7	12	32	58	36
15	9	18	27	62	30
16	12	16	23	61	30
17	10	15	28	55	35
18	12	12	28	70	33
19	11	12	24	71	37
20	14	15	22	54	42
			Intervention		
1	3	5	2	11	8
2	4	5	5	8	12
3	4	4	2	9	15
4	2	5	1	7	1
5	1	4	0	2	1
6	1	6	2	2	1
7	0	5	2	0	3
8	0	5	0	1	3
9	0	6	0	0	2
10	0	0	0	0	0
11	0	2	0	0	1
12	0	2	0	0	0
13	0	0	0	0	0
14	0	0	0	0	0
15	0	0	0	0	0

Raw Data--Subvocal Units *per* 10 Seconds, Continued

	Subject 1	Subject 2	Subject 3	Subject 4	Subject 5
16	0	0	0	0	0
17	0	0	0	0	0
18	0	0	0	0	0
19	0	0	0	0	0
20	0	0	0	0	0
21	0	0	0	0	0
22	0	0	0	0	0
23	0	0	0	0	0
24	0	0	0	0	0
25	0	0	0	0	0
26	0	0	0	0	0
27	0	0	0	0	0
28	0	0	0	0	0
29	0	0	0	0	0
30	0	0	0	0	0
31	0	0	0	0	0
32	0	0	0	0	0

Raw Data--Percentage Correct

	Subject 1	Subject 2	Subject 3	Subject 4	Subject 5
Baseline					
1	66	77	83	50	33
2	83	100	66	83	33
3	83	50	50	66	50
4	83	83	50	83	60
5	75	66	50	66	33
6	83	83	80	80	60
7	66	100	66	40	33
8	33	78	33	66	83
9	66	83	33	66	66
10	83	66	33	50	28
11	71	71	33	50	28
12	57	75	50	65	33
13	50	40	33	75	50
14	66	80	57	40	33
15	75	60	40	65	50
16	50	57	71	70	33
17	66	66	80	66	50
18	70	100	60	66	20
19	57	100	57	80	66
20	83	66	57	55	25
Intervention					
1	66	42	8	10	20
2	83	83	16	25	75
3	33	83	0	5	0
4	66	50	15	0	30
5	40	60	25	26	50
6	50	100	50	33	60
7	83	86	57	40	60
8	66	71	60	33	33
9	83	100	71	50	66
10	50	100	50	57	20
11	83	100	60	66	50
12	50	71	66	57	50
13	83	100	66	66	20
14	83	85	50	57	42
15	66	100	75	66	57

Raw Data--Percentage Correct, Continued

	Subject 1	Subject 2	Subject 3	Subject 4	Subject 5
16	83	86	40	71	28
17	100	73	66	50	25
18	57	70	33	70	60
19	68	85	42	85	66
20	68	50	57	66	50
21	66	70	57	66	57
22	66	87	66	66	33
23	85	50	40	80	20
24	71	40	42	83	66
25	71	80	66	66	40
26	87	66	66	50	71
27	83	80	83	66	33
28	66	60	50	50	66
29	83	90	40	80	75
30	33	85	66	83	70
31	57	100	55	66	66
32	66	66	50	50	50

Raw Data--Words Per Minute

	Subject 1	Subject 2	Subject 3	Subject 4	Subject 5
			Baseline		
1	153	276	177	123	177
2	163	273	174	122	174
3	130	257	170	117	146
4	122	224	168	103	151
5	143	272	185	116	159
6	148	288	122	117	161
7	159	257	162	121	183
8	137	261	170	130	178
9	153	273	185	105	191
10	128	281	181	127	169
11	127	277	182	131	151
12	116	253	189	116	153
13	140	280	175	122	171
14	138	254	174	106	191
15	140	271	153	128	186
16	145	269	182	110	191
17	122	257	177	124	152
18	117	250	170	122	160
19	137	281	152	113	173
20	153	224	182	118	145
			Intervention		
1	185	200	181	113	138
2	231	162	194	119	170
3	180	150	180	120	162
4	190	195	206	117	201
5	183	268	192	144	170
6	183	158	224	141	202
7	196	210	203	158	153
8	174	222	167	143	168
9	160	213	181	172	188
10	162	332	203	162	172
11	195	330	202	168	193
12	176	288	215	154	168
13	210	290	206	180	194
14	191	330	191	156	215
15	234	290	205	147	196

Raw Data--Words Per Minute, Continued

	Subject	Subject 2	Subject 3	Subject 4	Subject 5
16	201	208	203	146	223
17	209	316	222	140	224
18	205	285	243	149	234
19	207	293	230	157	225
20	197	336	250	160	223
21	210	292	221	141	215
22	241	328	232	148	222
23	226	309	250	165	280
24	220	310	240	155	201
25	210	304	241	158	227
26	227	325	236	165	225
27	209	321	231	178	227
28	210	299	221	161	200
29	223	308	215	157	217
30	217	310	235	159	218
31	210	330	252	170	213
32	221	316	220	146	226

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