tape recorder (center frequency of 3.12 kHz ± 1 percent) at $1\frac{7}{8}$ inch per second. The output of the tape recorder was monitored on a Tektronix 565 oscilloscope. Forty bipolar electrodes [dimensions determined after preparation: 31.05 ± 1.56 cm long (mean ± 1 standard deviation) with bared tips 2.16 ± 0.16 mm long] were formed from Teflon-coated stainless steel wire (Medwire), 0.076 mm in diameter. Each electrode pair was passed through the shaft of a hypodermic needle (14 cm long, 22 gauge) with an interdermal point. The insertion depth was marked by a gauge 1.5 cm from the tip of the needle. Cats were anesthetized by an intramuscular injection of ketamine hydrochloride (Vetalar). Three electrodes were inserted into the deep temporalis muscle on both sides through a 1-cm skin incision over the middorsal origin of each muscle. The first needle and its electrode were directed straight downward for 1.5 cm along the bony cranial wall. The needle was left in place while a second and third were inserted to the same depth anteriorly and posteriorly to the first. Then all three needles were removed. The electrode wire was kinked at the incision site and passed subdermally to the dorsum of the neck where it was soldered to a connector. The shoulder was then wrapped with an elastic bandage to minimize intramuscular movement of the electrode tips due to displacement of the connecting wires. Tests occurred 24 hours after electrode implantation. The EMG signals were stored on tape. Synchronized 16-mm motion pictures and voice records indicated the chewing side as well as the start and end of each reduction sequence. Cats were fed pieces of cooked beef (2 by 2 by 1 cm). The taped records of 33 reduction sequences were then processed by a computer that sampled four channels of EMG's for sequential 30-msec intervals.

4. G. C. Gorniak and C. Gans, *J. Morphol.* **163**, 252 (1980).
5. ______, J. A. Faulkner, *Science* **204**, 1085 (1979).
6. The actual durations of electrical events will differ depending on the site from which the signal is recorded—within one muscle fiber, among fibers of a motor unit, or outside the field of a motor unit [F. Buchthal and H. Schmalbruch, *Physiol. Rev.* **60**, 90 (1980)]; C. J. LeLuca, *IEEE Trans. Biomed. Eng.* **26**, 313 (1979).
7. Three electrodes were tested for each of the nine possible configurations of the seven wire types (Table 2). All electrodes were formed under a dissecting microscope by G.C.G. by a variation of the method of R. G. Scott and G. B. Thompson [*Med. Biol. Eng.* **7**, 677 (1969)]. Reference electrodes were formed from Teflon-coated platinum-iridium wire (Medwire), 0.03 mm in diameter. The middle of a length of wire was lifted off the working surface, forming a loop that was placed on a hook mounted in a drill chuck. The two sides were pinched tightly together, approximately 2 cm from the top of the loop and twisted about each other by manual rotation of the chuck. The loop was then removed from the hook, and the required length of insulation (as measured with a millimeter scale) was stripped from the wire on one side, close to the twisted portion facing the top of the loop. Twisting continued until half of the bared area was within the twisted part. The loop was then cut at the junction between the bared and insulated area; this produced one tip of the bipolar electrode. Next, an equal length of insulation was removed from the other side, starting across from the end of the first tip. The second tip was then cut where bared and insulated sections met. Both tips of the electrode were bent back toward the twisted zone, forming a double hook and leaving the bared stretch of one tip opposite an insulated zone on the second tip; this made contact between the bared zones unlikely. The insulation was always removed by scraping the wire between the tips of fine forceps. This lessened the possibility that the properties of the wire might be altered, as when insulation is removed by chemicals or flame. Teflon, polyurethane, and H-ML insulation are removed easily; however, enamel insulation adheres to the wire.
8. Each electrode was soldered directly to an Amphenol MS 3101A connector. Signals to be monitored were generated by a Grass S44 stimulator and transmitted to two 0.115 mm solid stainless steel wires placed into the gel. Signals from the test electrodes were amplified 1000 times through Tektronix 26A2 preamplifiers and stored on a Sony TC-788-4 four-channel tape recorder at a tape speed of 7.5 inches per second. Stimulator settings were 1- or 5-mV amplitude, frequencies 100, 500, or 1000 Hz, and signal durations 0.01, 0.1 or 1 msec. The system was calibrated at different signal frequencies and magnitudes by placing an electrode pair on a plate of conductive gel, preamplifying the signal received, and monitoring it from the output channel of the tape recorder. The signal of the electrode was passed to three tape channels and preamplifiers and amplifiers adjusted to obtain equal outputs. For each test, the bared tips of three electrodes were placed on the surface of a circular plate of gel (9.5 cm in diameter) that was subdivided into quadrants. Each quadrant was used for only one test, and the gel was covered between tests to minimize desiccation, which might affect the conductance of a signal through the medium. The electrode tips were arranged horizontally to fit a rectangle (3 by 1 cm) and were held steady by a weighted glass plate. Positions of recording electrodes were set so that the signal displayed did not change more than 1 percent when the stimulating electrode was moved 1 cm in any direction. Change of impedance was estimated from the change in the peak to peak voltages noted on a Tektronix 564B storage oscilloscope.
9. Major sources of information on electrodes, their impedance, difference among metals, and electrode-electrolytic interaction include J. M. R. Delgado, in *Physical Techniques in Biological Research*, W. L. Nastuk, Ed. (Academic Press, London, 1964), vol. 5, p. 88; C. D. Ferris, *Introduction to Bioelectrodes* (Plenum, New York, 1974); L. A. Geddes, *Electrodes and the Measurement of Biolectric Events* (Wiley, New York, 1972); N. A. Miller and D. C. Harrison, Eds., *Biomedical Electrode Technology* (Academic Press, London, 1974). We tested fine wire electrodes directly in an arrangement with preamplifiers with a high-input impedance. Most investigators now use such a recording arrangement to obtain EMG records. The question is whether differences in the type or material of the electrodes can induce sufficient differences in such a system to justify the claim of nonrepeatability.
10. This effect (producing a drop in amplitude) was easily demonstrated by temporarily cooling the junction between the electrode wire and the cables with a compressed air spray during recording sessions.
11. Copper is very toxic to living tissue, as are both bare and chloride-coated silver. Both copper and silver progressively destroy the surrounding tissue from the time they are introduced until they are removed; severe tissue destruction can occur in a few days. Thus, EMG's recorded from copper or silver electrodes may differ sequentially from day to day. In contrast, stainless steel produces only a temporary inflammatory response in the tissue, but there is no progressive tissue destruction. It seems useful to emphasize that the insulating material, as well as the metal should be biologically inert [J. M. R. Delgado, in (*9*); P. L. Blanton, R. P. Lehr, J. H. Martin, N. L. Biggs, *Electromyography* **11**, 475 (1971)].
12. S. W. Herring, A. F. Grimm, B. R. Grimm, *Am. J. Anat.* **154**, 563 (1979); L. C. Maxwell, D. S. Carlson, J. A. McNamara, Jr., J. A. Faulkner, *Anat. Rec.* **193**, 389 (1979).
13. Orientation of bipolar electrodes may also affect the recorded voltage as the resistivity of muscle is greater across than along muscle fibers. The durations of recorded muscle action potentials are shorter and their amplitudes greater when the tips of a bipolar electrode are parallel to the fibers than when they are perpendicular to them [F. Buchthal, C. Guld, P. Rosenfalck, *Acta Physiol. Scand.* **38**, 331 (1957); F. Buchthal, F. Ermino, P. Rosenfalck, *ibid.* **45**, 72 (1959); W. Waring, in *Biomedical Electrode Technology*, N. A. Miller and D. C. Harrison, Eds. (Academic Press, London, 1974), p. 215].
14. This implies among other things that muscles that fire twice during a jaw movement or limb rotation cycle may show different correlations between the EMG amplitude and the force generated for each activity phase [B. Walmsley, J. A. Hodgson, R. E. Burke, *J. Neurophysiol.* **41**, 1203 (1978); M. C. Wetzel and D. G. Stuart, in *Mechanics and Energetics of Animal Locomotion*, R. McN. Alexander and G. Goldspink, Eds. (Chapman & Hall, London, 1977), p. 115].
15. We thank K. Guthe, R. A. Nussbaum, R. J. Lowry, and T. Scanlon for discussion; A. English for the gift of the Cooner wire; and J. V. Basmajian, D. Cundall, C. J. De Luca, A. English, A. S. Gaunt, G. E. Goslow, F. C. Kallen, S. Kashin, G. E. Loeb, T. Scanlon, and D. Stuart for their perceptive and helpful criticisms of early versions of this manuscript. Supported by NSF grant DEB 77-02605 and NIH grant DHEW-PHS-G 1R01DE052112-01.

28 April 1980; revised 17 July 1980

Bandwidth Requirements for Video Transmission of American Sign Language and Finger Spelling

Abstract. *Although current video communication schemes use a bandwidth on the order of 1 megahertz, the bandwidth required for video communication of American Sign Language by a simple raster scan is only approximately 20 kilohertz.*

Alexander Graham Bell invented the telephone in the course of his research on a hearing aid for the deaf (*1*), but the telephone has primarily served the hearing community. With more than 2 million severely deaf Americans who are unable to understand speech even with a hearing aid (*2*), it is appropriate for current research to find a means of adapting the transmission facilities already established for voice communication by telephone to the needs and habits of the deaf community. The most common methods of linguistic interaction among the congenitally deaf are American Sign Language (ASL), finger spelling (used where no sign exists in ASL, such as for proper names or technical terms), and speech reading (*3*).

Two existing devices that provide telecommunication for the deaf are the teletypewriter and the video telephone. Teletypewriters (*4*) enable a sender to transmit a typewriter message to a receiver, who sees the characters displayed on a screen or produced on another teletypewriter. The teletypewriter is useful for communication between deaf and hearing people, perhaps in conjunction with a voice channel for those deaf who retain intelligible speech. But the teletypewriter has a practical disadvantage: communication is slow and effortful compared with voice or ASL communication, which is about as fast as voice (*5*). The video telephone is far more attractive than the teletypewriter to many deaf persons for communication among themselves (*6*).

The American video telephone [Picturephone (*7*)] and the British version [Viewphone (*8*)] both transmit a picture

0036-8075/80/1114-0797$00.50/0

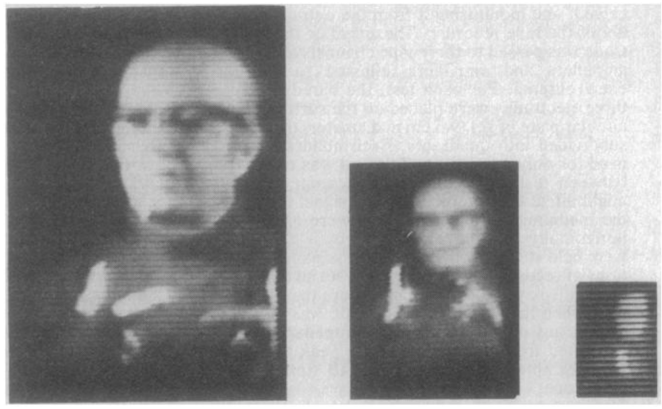

Fig. 1. Photographs of the television display at the three highest bandwidth conditions. (A) 86,000 Hz. (B) 21,000 Hz. (C) 4,400 Hz. Exposure: 1/10 second. The actual sizes of the three displays were 5.8 by 8.1 cm, 2.9 by 4.3 cm, and 1.31 by 1.96 cm. Because of quality losses in photography and in reproduction, the subjective quality of these photographs corresponds more nearly to the three lowest bandwidth conditions.

of the sender to the reader by means of a television raster scan. Unfortunately, Picturephone and Viewphone require a communication bandwidth of 10^6 Hz [compared with 3000 Hz (*9*) for a telephone voice communication channel]. Their enormous bandwidth appetite not only makes them unsuitable for existing telephone transmission and switching facilities, but it makes the development of video telephone facilities economically unattractive. Present research is aimed at answering the question posed by Sperling (*10*): What are the minimum requirements for a video telephone having a lower picture quality than Picturephone or Viewphone but, consequently, a lower bandwidth so that it could utilize existing telephone channels?

Even if the technical resources were available, it would not be necessary to actually build a low-bandwidth transmission channel in order to discover its properties; it can be simulated by using ordinary television. American television uses a raster scan of 525 lines per picture, produces 30 full pictures per second, and has a bandwidth of 4×10^6 Hz (*11*). A small, rectangular subarea of the full picture represents a smaller channel; the subarea uses a fraction of the full bandwidth corresponding to the fraction of the full area it actually occupies. By recording a signer who is communicating in ASL or finger spelling and by confining the recording to a known, small area of a television picture, the bandwidth allocated to the ASL transmission can be readily computed. Of course, the full television transmission and recording system must first be calibrated to determine its true bandwidth (*12*).

The signer for this study stood behind a screen with a 12 by 18 inch (30.5 by 45.7 cm) aperture and produced ASL and finger spelling within the area of the aperture. Television recordings of the signer were made at four combinations of lens and camera distances to produce four bandwidth conditions: 86,000, 21,000, 4,400, and 1,100 Hz (Fig. 1) (*13*).

Four equivalent sets of stimulus materials based on vocabulary in a popular ASL textbook (*14*) were recorded. Each set contained (i) 30 nouns (for example, "son, coffee, morning"; "pants, people, face"; "autumn, paper, parents") and ten sentences (such as "Your book impresses me." "I need another stamp." "Sleepy girl doesn't want bath tonight.") produced in ASL and (ii) five finger-spelled family names and five finger-spelled city names. (such as "Gilstrap," "Quigley," "El Paso," "Elmhurst").

In order to secure a heterogeneous sample of deaf subjects, tests were conducted at three places: two clerical employees were tested at an industrial laboratory; two employees and a graduate student were tested at the New York University Deafness Research and Training Center; and 17 subjects who responded to a call for subjects at a Brooklyn, New York, social club were tested at another New York University location. This last group of subjects consisted primarily of older persons and included six housewives, five retired persons, a teacher's assistant, a clerk, a machine operator, a printer, an unemployed printer, and a disabled printer. One housewife and one retired man did not know ASL and finger spelling; their data are omitted from the analysis.

Subjects were tested individually. They viewed the television display at a distance of from 1 to 3 feet (as they preferred), and after each triplet of nouns, each sentence, or each name, wrote down what they perceived of the transmission. The written responses were scored for the fraction of items reported correctly.

As bandwidth decreased, intelligibility decreased (Fig. 2). The highest bandwidth (86 kHz) was the control: errors that occurred at this bandwidth were attributable primarily to unfamiliarity with the particular ASL sign used, to lapses of attention and memory, and, in the case of finger spelling, to the inability of some subjects to perfectly comprehend words produced at rates of three or four letters per second. The scatter of data points represents the large variation in language skill that exists among the deaf; individual measurements are reproducible.

Median ASL intelligibility at 21 kHz

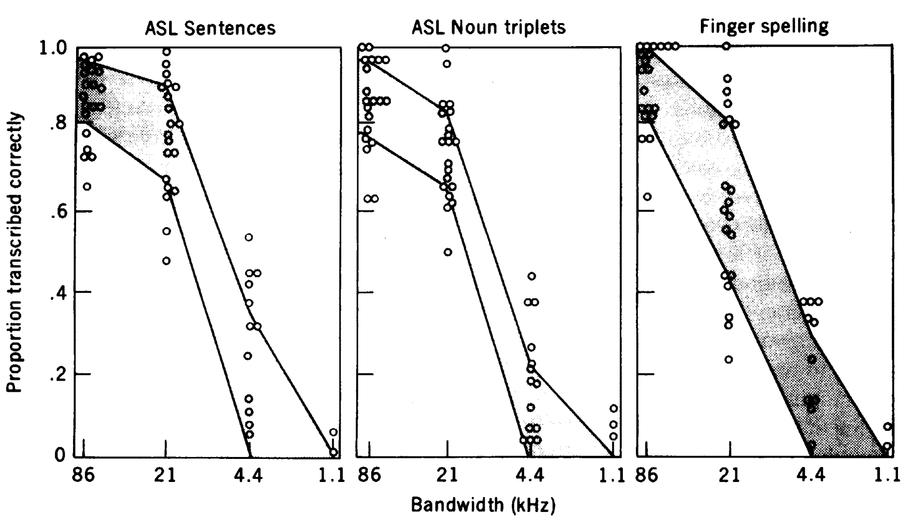

Fig. 2. The proportion of correctly transcribed items as a function of display bandwidth. Each data point represents the score of one of the 20 subjects in one condition. Subjects were excused from tests when it was obvious their scores would be near zero; only scores of tests actually taken are shown. The shaded area represents the performance of the middle 50 percent of subjects.

was about 90 percent of the control value. The loss at 21 kHz was somewhat greater for finger spelling. The best subjects (which include four of the five laboratory and university employees and just two or three of the others) were generally the youngest subjects in this sample: their ASL performance at 4.4 kHz was 40 to 50 percent of control. Their performance at 4.4 kHz is about what would be obtained with hearing subjects listening to voice communication over a 1.5-kHz (low-pass) channel (*15*). Thus, while a television picture may use more than 1000 times the bandwidth of a telephone line, visual transmission of ASL requires only a few times more bandwidth than voice communication.

The minimum bandwidth required for the video transmission of ASL by a raster scan is not known; the design of the present study yields only an upper bound. A more judicious choice of raster variables (fewer frames per second, more lines per frame, interlace, and so forth) would almost certainly reduce this upper bound substantially. The low bandwidth—the low information rate—makes possible more advanced picture coding by any of many schemes to further reduce the bandwidth.

Present video transmission systems thus use a much wider bandwidth than is required for transmission of ASL. By a sevenfold further reduction in the bandwidth required for ASL transmission or by a sevenfold increase in the bandwidth that can be carried on telephone facilities, the ASL-signing deaf population could—with appropriate video terminals—use our present telecommunication facilities for ASL communication.

GEORGE SPERLING
Department of Psychology,
New York University,
New York 10003

References and Notes

1. M. D. Fagen, Ed., *A History of Engineering and Science in the Bell System: The Early Years (1825-1925)* (Bell Laboratories, Murray Hill, N.J., 1975).
2. J. D. Schein and M. T. Delk, Jr., *The Deaf Population of the United States* (National Association of the Deaf, Silver Spring, Md., 1974).
3. H. Bornstein, in *Sign Language of the Deaf*, I. M. Schlesinger and L. Namir, Eds. (Academic Press, New York, 1978), pp. 333-361.
4. P. A. Bellefleur, *Volta Rev.* **78**, 107 (1976).
5. U. Bellugi and S. Fischer, *Cognition* **1**, 173 (1972); U. Bellugi and E. S. Klima, in *Deaf Children: Developmental Perspectives*, L. Liben, Ed. (Academic Press, New York, 1978), pp. 43-68.
6. D. E. Pearson, *J. R. Telev. Soc.* **16**, 6 (1978).
7. I. Dorros, *Bell System Tech. J.* **50**, 221 (1971); T. V. Crater, *ibid.*, p. 235.
8. G. A. Gerrard and J. E. Thompson, *Radio Electron. Eng.* **43**, 201 (1973).
9. Technical Staff, Bell Telephone Laboratories, *Transmission Systems for Communications* (Western Electric Company, Inc. Technical Publication, Winston-Salem, N.C., rev. ed. 4, 1971).
10. G. Sperling, in *Deaf Children: Developmental Perspectives*, L. Liben, Ed. (Academic Press, New York, 1978), pp. 103-114.
11. D. E. Pearson, *Transmission and Display of Pictorial Information* (Wiley, New York, 1975).
12. The recordings were made with a camera (Panasonic WV204P) having 4-mm and 8-mm lenses (Apollo) and with a cassette recorder (Sony V0-2800). The playback monitor was a 17-inch cathode-ray tube (Conrac QQA 17/N). For bandwidth calibration, vertical gratings that produced different numbers of cycles per centimeter on the monitor were recorded, and their modulation depth was measured with a microphotometer. Modulation depth diminished sharply to 50 percent of the maximum depth for coarse gratings at 2.0 ± 0.1 MHz. The sharp cutoff at 2 MHz was caused by the recorder; the camera and monitor easily passed 4 MHz. Recordings were made without interlace, producing 60 full pictures per second.
13. The number of horizontal raster lines in the four bandwidth conditions, respectively, was 79, 38, 17, and 9. (The full, noninterlaced television picture contained 262 lines.)
14. T. J. O'Rourke, *A Basic Course in Manual Communication* (National Association of the Deaf, Silver Spring, Md., ed. 2, 1973).
15. N. R. French and J. C. Steinberg, *J. Acoust. Soc. Am.* **19**, 90 (1947).
16. I thank E. Bloom, Jr., a deaf retired chemist, for acting as the signer for this study.

31 December 1979

Electroconvulsive Shock: Progressive Dopamine Autoreceptor Subsensitivity Independent of Repeated Treatment

Abstract. *Repeated electroconvulsive shock, applied to rats, induces a subsensitivity of dopamine autoreceptors located in the substantia nigra as indexed by single-unit electrophysiological techniques. This reduced sensitivity is time-dependent, since effects similar to those seen with repeated treatment were also observed when single electroconvulsive shock was followed by an appropriate treatment-free interval. These data, coupled with identical results after the repeated administration of tricyclic antidepressants, raise the possibility that a reduction of dopamine autoreceptor sensitivity could underlie both electroconvulsive shock and pharmacological treatment of depression.*

Electroconvulsive shock (ECS) is generally thought to be the most effective means of treating endogenous depression (*1*). It affects a variety of putative neurotransmitter or neuromodulator substances including norepinephrine, dopamine, serotonin, γ-aminobutyric acid, and the endorphins (*2*). Considerable attention has recently been directed toward receptor mechanisms possibly underlying the therapeutic efficacy of both ECS and the tricyclic antidepressants (TCA's) (*3*); the focal point of this research has been the norepinephrine system. Several studies have now demonstrated changes indicating decreased β-adrenergic receptor function after repeated treatment with either ECS or TCA's (*4*). Our own recent research has shown that repeated TCA administration induces a progressive subsensitivity of dopamine autoreceptors [dopamine receptors on the soma and dendrites of dopamine-containing neurons located in the zona compacta of the substantia nigra (SNC)] independent of daily drug administration (*5*). In light of these findings we inquired whether ECS could produce similar effects. We now report that ECS also gradually reduces dopamine autoreceptor sensitivity and that this process depends on the passage of time rather than on repeated shock treatment.

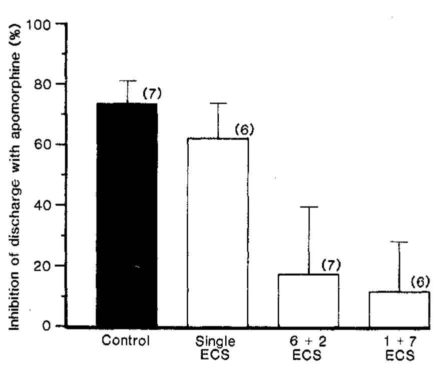

Fig. 1. The effects of various ECS treatments on the apomorphine-induced (0.004 mg/kg, intravenously) inhibition of the spontaneous activity of dopaminergic neurons of the SNC (*16*). For each treatment, *N* is shown in parentheses. Abbreviations: *1 + 7 ECS*, single ECS followed by 7 days without treatment; *6 + 2 ECS*, six daily ECS's followed by 2 days without treatment.

Twenty-seven male albino rats (200 to 250 g; Zivic-Miller) housed two per cage with free access to food and water were maintained on a 12-hour light/dark cycle. After a period of ECS treatment the animals were anesthetized with chloral hydrate (400 mg per kilogram of body weight, injected intraperitoneally), and the electrophysiological activity of dopaminergic neurons located within the SNC [anterior 1300 to 2400 μm, lateral 1300 to 2400 μm (*6*)] was monitored (*7*). Briefly, single unit neuronal activity was recorded through glass micropipettes filled with 2*M* NaCl saturated with Fast Green dye (in vivo impedance, 8 to 15 megohms). Action potentials were fed