Table 1. Ratio of the area of the threshold target to that of the standard target at three distances for each subject.

Distance (inches)	Subject			
	CB	DB	WG	DD
24 (61 cm)	1.11/1	1.08/1	1.10/1	1.23/1
36 (91 cm)	1.08/1	1.12/1	1.07/1	1.22/1
48 (122 cm)	1.09/1	1.08/1	1.12/1	1.10/1

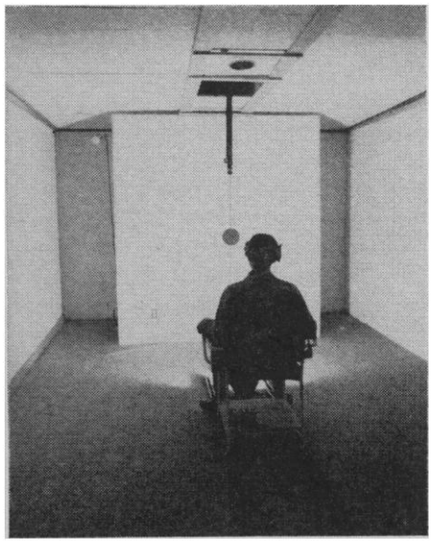

Fig. 1. Room used for testing, with subject and apparatus in position for a judgment.

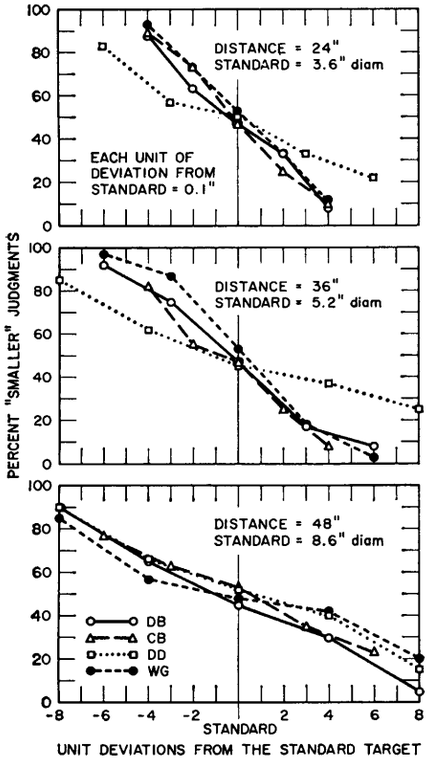

Fig. 2. Probability of a "smaller" judgment by each of four subjects at three distances when targets were compared to the standard.

(Fig. 1) which could be adjusted for the required heights and distances from the target. White noise was provided between trials in order to mask possible undesirable sound cues.

The subjects were tested at three distances from the targets: 24 inches (60.96 cm), 36 inches (91.44 cm), and 48 inches (121.92 cm) so that information on the effect of distance and auditory angle upon the size discrimination could be obtained. At each distance, a range of five target sizes was presented to the subject by the method of constant stimuli. The middle-sized target of the range was designated as a standard stimulus. This standard was randomly compared with itself and each of the other targets until each pairing had occurred 60 times. The order of presentation was counterbalanced with the standard occurring first and second on an equal number of trials. The subjects were instructed to emit their typical echo-detection noise upon presentation of each target and to make a judgement as to whether the second target of the pair was "larger" or "smaller" than the first. If, therefore, this second target seemed larger than the first, the subject's response were "larger," and vice versa.

The subjects were trained briefly with target discs which were much larger or smaller than the standard. As their performances improved this size difference was reduced until five targets were found which offered a good test of ability. Each range of targets was composed of: (i) a middle target or standard; (ii) two targets which deviated from the standard by plus and minus a given number of units in diameter (each unit equals 0.1 inch or 0.254 cm); and (iii) two targets deviating plus and minus twice as many units as in (ii). The actual range of difference in targets was governed by the distance of a given subject from the target and his skill at the task.

Figure 2 relates target size to the probability of a "smaller" judgement by each subject at the three distances. As the distance of subjects from the targets increased, the amount of deviation from the standard target necessary for the change in size to be perceived increased.

An estimate of the minimum amount of increase or decrease in target size which would be just noticeable may be made by calculating the standard deviation of the "smaller" judgements for a given size range (*2*). From this value an estimate can be made of the size of the target just perceptibly larger or smaller than the standard. This hypothetical target is referred to as a difference "threshold" target. Such a threshold target for each subject at each distance was calculated and the ratios of the areas of these targets to the standard target are shown in Table 1. The ratio of the size of the threshold target to the standard was relatively constant regardless of distance. This leads to the hypothesis that the difference threshold for size by echo-detection is a constant size ratio.

We conclude that the human ear is capable of making relatively fine size discriminations from echo-information. The precise stimulus parameter on which these discriminations are made is as yet unknown. Preliminary evidence from current experimentation leads to the hypothesis that echo intensity is a probable cue. The degree of acuity for the task reported here is equal to that of thresholds of visual differences reported for monkeys (*3*) and sea lions (*4*), both regarded as animals with fairly good vision. Sighted humans, however, had no difficulty in making the visual discrimination among targets in this task.

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Galvanic Skin Reflex in Newborn Humans

Abstract. *Psychophysiological recordings of reactivity to light and sound and to tactile and olfactory stimulation demonstrate that the galvanic skin reflex is an observable and functional mechanism in the 20- to 67-hour-old newborn human.*

Though originally purported by Peiper (*1*) to be undeveloped until 12 months after birth, the galvanic skin reflex (GSR) was subsequently dem-

onstrated in infants aged 3 to 11 months by Jones (*2*) and interpreted as evidence for ". . . the functional completeness of the arcs involved . . . at least as early as 3 months of age." (*2*, pp. 109–110). A program of multivariate psychophysiological recordings of reactivity to sensory stimulation now supplies evidence that the GSR occurs in human neonates soon after birth (Fig. 1).

We have analyzed the records of ten clinically normal full-term infants in an effort to quantify significant resistance changes coincident with or subsequent to stimulation. The infants, five of whom were males, were seen twice, first between 20 and 43 hours after birth and again 24 hours later. Mean ages of these subjects were 29½ hours on day 1 and 53½ hours on day 2. Mean male and female birth weights were 3.5 and 3.2 kg, respectively. The deliveries of eight of the infants were normal and spontaneous; two, both males, were delivered by caesarean section.

Electrodermal responses to stimuli were recorded from the plantar surface of the left foot and the left dorsal mid-calf by means of a Fels dermohmmeter, Model 22A, constant impressed current of 40 μa and the output monitored by an Offner Type R dynograph. The electrodes were zinc plates, 13 mm in diameter, set into plastic cups with outer diameters of 15 mm, depths of 9 mm, and cup rims 1 mm wide, filled with a mild zinc sulfate paste (*3*).

Leads were connected through the top of the plastic cup and sealed with Epoxy plastic. Before use, the metal surface of each electrode was polished with No. 0000 steel wool. The plantar surface below the metatarsal bones and the mid-calf region were wiped with cotton soaked in warm water, then dried, and the electrodes firmly fastened to these areas with Elastoplast tape. Before recording we allowed a hydration period of 10 minutes. For the electrodes used, the constant current of 40 μa had been empirically determined to produce a signal that could be recorded without the infants being irritated or subjected to discomfort.

The schedule of stimulation was as follows. (i) A 40-watt incandescent light (L_1) placed at a distance of 61 cm in line with the subject's eyes was turned on for 3 seconds. (ii) Pure tones at 500, 1000, 2000, 4000, 6000, and 8000 cy/sec, at 50 db (S_1), were presented for 4 seconds; the sound being produced by a Beltone audiometer, model 10A, sound reference level 0.0002 dyne/cm^2, and modulated at 5 percent of the basic frequency at a rate of 6 cy/sec by an Allison warble tone adapter, model 101. (iii) A 75-watt incandescent light (L_2) was turned on, the conditions being as described for L_1. (iv) Modulated pure tones at an 80 db level (S_2) were presented under similar conditions as for S_1. (v) A puff of nitrogen (N) at 1.68 atm was applied to the abdomen above the umbilicus for 0.5 second. (vi) Auditory clicks (AC) were delivered at a rate of 5 per second from a Grass PS-2 photic stimulator synchronization circuit amplified at 50 db. (vii) Glacial acetic acid (O) was presented with a cotton Q-tip, 5 mm from the subject's nares for 2 seconds. (viii) Repetitive photic stimulation at a rate of three flashes per second was given for 6 seconds from a Grass PS-2 photic stimulator, intensity 8, with the lamp 25 cm from the subject's eyes. (ix) An electrotactual stimulus of 4 cy/sec for 0.5 second beginning at 60 v was presented until the threshold criterion of two consecutive foot or leg movements were made. (x) Three single flashes from the photic stimulator were presented, the settings being the same as for repetitive stimulation, with a 1-second interval between the first and second flashes and a 3-second interval between the second and third flashes.

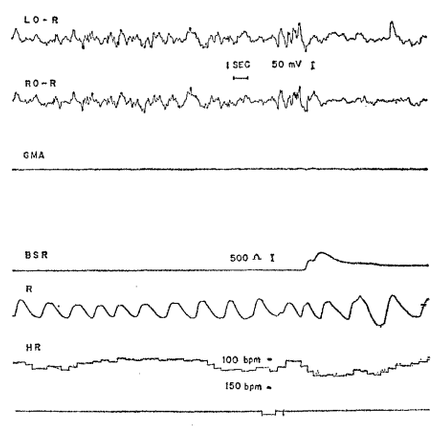

Fig. 1. Polygraphic tracings of responses of newborn human male, aged 60 hours, to stimulation. Variables recorded, from top to bottom, are EEG (left and right occipital to the Rolandic area), gross motor activity (GMA), basal skin resistance (BSR), respiration (R), and heart rate (HR). Paper speed, 10 mm/sec. Galvanic skin reflex to a puff of nitrogen, 1.68 atm applied to the abdomen above the umbilicus for 0.5 second. Stimulation followed a timed interval of 1 second, programmed to ensure controlled presentation when the infant was quiet.

Table 1. Mean values for galvanic skin responses of infants to classes of stimuli.

Stimuli	Amplitude*	Latency (sec)	Rise time† (sec)	Absolute recovery time (sec)
$L_1 + L_2$	0.91	0.7	1.9	2.4
$S_1 + S_2$	1.20	1.4	8.9	3.7
N	1.20	1.0	4.6	3.8
AC	1.16	1.3	5.2	2.7
O	1.24	1.1	3.0	2.8

* Difference between GSR baseline and GSR peak amplitude in conductance units. † Time taken for the response to reach maximum amplitude.

Approximately 45 seconds elapsed between stimuli presentations which were given when the subject was quiet. All stimuli but one were electronically presented and recorded. The olfactory stimulus was presented manually in synchrony with the timed event marker. Mean ambient temperature was 22.8°C and mean relative humidity was 64 percent.

A GSR was defined as occurring if the skin resistance decreased at least 2 mm (200 ohms) within 20 seconds of the onset of the stimulus and if the time taken for the response to reach maximum amplitude was within 5 seconds. For the observed GSR's the following points were measured: skin resistance just prior to the response (GSR response baseline); maximum amplitude of the decrease from the response baseline (GSR response amplitude); skin resistance at the end of the response (GSR recovery); time from stimulus onset to the beginning of the response (GSR latency); time, not to exceed 5 seconds, from the onset of the response to its maximum amplitude (GSR rise time), and time from response peak to the end of the response (GSR recovery latency). Because all responses did not return rapidly to the GSR baseline determined before stimulation was begun, the response was further defined as being ended when a 1-mm change from the GSR peak amplitude was maintained for a minimum of 3 seconds. If the response had not ended by 25 seconds after stimulation, this 25-second point was arbitrarily chosen as the recovery level. In addition to these, the basal skin resistance at time of stimulus onset was measured for all subjects. These measurements were recorded for the L_1 and L_2, S_1 and S_2, N, AC, and O

presentations for a total of 17 stimuli on each of 18 records over 2 days. Two records were rejected because of electrode leakage. All resistance measures were transformed to conductance units (C) by the formula $C = 10^5 R^{-1/2}$, where R represents resistance in ohms (*4*).

There were 54 conductance changes (Fig. 2) which met the basic criteria for a GSR; these constituted 18 percent of the total 306 stimulations. For the 54 GSR's the percentage distribution of response to classes of stimuli was L_1, 4 percent; S_1, 19; L_2, 4; S_2, 26; N, 11; AC, 19; and O, 19. Of the specific stimuli, both AC and O produced GSR's in 10 out of 18 presentations.

The immediate problem prior to any statistical treatment of these data was an evaluation of whether the observed GSR's were due to changes in skin resistance or due to artifacts caused by spontaneous movement of the leg, foot, or toes which might in turn move the electrodes. Inasmuch as the gross motor channel tracing represented a composite signal of body activity from the X and Y axes on the horizontal plane of the stabilimeter (*5*), foot and leg flexion-extension movements relative to resistance decreases were more directly measured by means of a modified Offner respiratory transducer. This flexible V-shaped flat metal bar with two strain gages bonded to a leg of the V, one on each surface, was inverted and one end screwed to the stabilimeter cradle. A rayon-covered elastic cord attached to the free end of the transducer was taped to the infant's left foot proximal to the plantar electrode so that leg or foot movements would cause the metal strip to flex with consequent excitation of the strain gages. Approximately 2.5 mm of foot-leg movement was equivalent to 1-mm deflection on the Offner dynograph channel. This more sensitive transducer showed that it was possible to get conductance changes simultaneously with large leg movements; however, leg movements of the amplitude observed in the recording sessions did not ordinarily produce the GSR-like phenomenon. Clear artifacts could be seen by pressing on the electrodes. It should be emphasized that the small-sized electrodes ensured constant contact and that, by virtue of their positions, it seemed unlikely that the electrodes were generally subjected to such outside forces. Further, control over this type of artifact was maintained by a visual check for electrode displacement after each recording. Results of two subjects were rejected because of such displacement and associated leak of paste.

Although it is possible that the recorded resistance changes were associated with movement, we do not believe that the tabulated GSR's are artifacts of movement. In fact, GSR's and movement probably do occur simultaneously, since the more potent stimuli seemed to evoke a generalized response pattern. Figure 3 shows an example of a GSR at (*A*); at (*B*) however, the response would not be labeled a GSR and would be considered movement artifact.

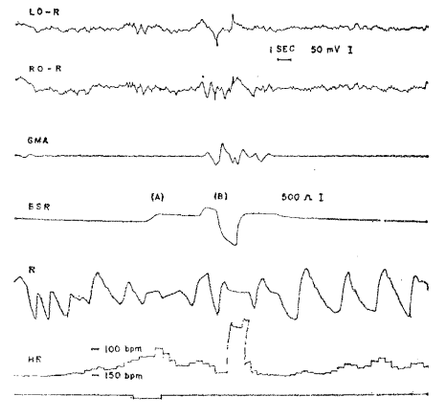

Fig. 3. Polygraphic tracings of responses of newborn human female, age 43 hours, to stimulation. Variables recorded, from top to bottom, are EEG (left and right occipital to the Rolandic area), gross motor activity (GMA), basal skin resistance (BSR), respiration (R), and heart rate (HR). Paper speed 10 mm/sec. (*A*) GSR to glacial acetic acid presented 5 mm from nares for 2 seconds. (*B*) Deflections in basal resistance tracing which would be described as movement artifact, and not illustrative of a GSR; this artifact is also reflected in the cardiotachometer signal.

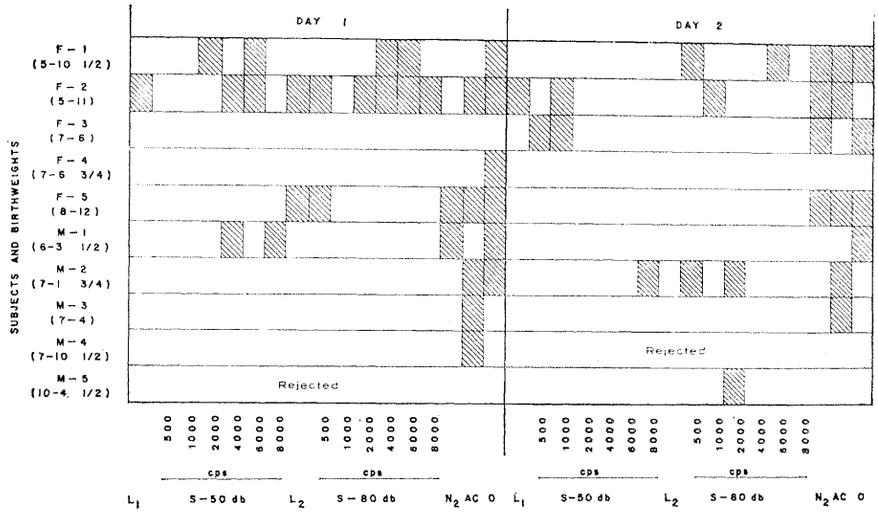

Fig. 2. Frequency pattern of GSR (diagonal stripe) to stimulation for individual male (M) and female (F) infants on day 1 and day 2.

While GSR's were produced by all stimulus modalities, it seemed inappropriate, with the exception of response latency, to combine or compare data from stimuli of such varying duration. Mean GSR latencies of the combined sound stimuli—that is, S_1 and S_2 were significantly different from all other stimuli, by the Kruskal-Wallis one-way analysis of variance (*6*), $H = 22.2816$, 4 degrees of freedom, $p < .001$. These combined sound latencies were significantly longer than the other classes of stimuli at probabilities of $< .05$ for combined sound versus nitrogen puff, $< .04$ for combined sound versus auditory clicks, $< .005$ for combined sound versus combined light, and $< .0005$ for combined sound versus the olfactory stimulus [Mann-Whitney U-test (*6*)]. Latencies for all other stimuli were not significantly different from each other.

The mean rise times, mean conductance response amplitudes, and median absolute recovery times are presented in Table 1. The GSR recovery is best depicted by a series of curves varying from a level almost asymptotic with the peak amplitude to a rapid decrease in conductance back to the original GSR baseline. Frequency of response was significantly related to sex, $\chi^2 = 6.075$,

$df = 1$, $p < .05$, with females producing more GSR's, but not to birthweight or base conductance level. The GSR magnitude, however, was significantly correlated with conductance baseline level, $r = +0.29$, $p < .05$.

Regardless of the exact neurophysiological mechanism directly responsible for the GSR (*7*), our data can be most parsimoniously interpreted as evidence that this mechanism is functional in the human infant as early as the first 24 hours after birth. In view of the dependence of the GSR on sweat gland activity, it should be noted that histologically the sweat glands appear to be capable of functioning as early as the 7th month of prenatal development, and further, that the sweat glands are functional at birth, with sensible perspiration demonstrable in response to the whole body's being heated on the day of birth (*8*).

Just as other neonatal autonomic responses to classes of stimuli have been observed (*9*), it appears that similar groups of stimuli will elicit the GSR. The response fluctuation within modalities and across days is not congruent with data for adults (*10*) in which the high probability of response evocation has made the GSR a frequent dependent variable in conditioning experiments (*11*). The question of the relatively low proportion of responses to stimuli cannot be answered by these data for infants, but it might be hypothesized that the threshold for GSR's is some function of position on the asleep-awake continuum (*12*). Although the positive correlation between the magnitude of the neonatal GSR response and conductance base level is in accord with results of Hord, Johnson, and Lubin (*13*), it does not follow the law of initial values (*14*) as it is usually interpreted.

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1 March 1965

Brain Telestimulator with Solar Cell Power Supply

Abstract. *A telestimulator has been constructed which is suitable for mounting on the heads of medium-sized* Macaca mulatta *or larger primates. It differs from previous units in that the battery supply is continuously recharged from ambient light by means of solar cells. The system features remote control of all stimulus parameters, constant current output, and remote selection of any of 11 electrodes. If additional transmitters are employed, simultaneous and independent stimulation of a number of primates in the same group is possible. A shielded room with a terminated antenna system is used to produce a homogeneous radio-frequency field for laboratory use.*

The ideal telestimulator for the primate brain should operate in the laboratory or in the field for long periods of time without requiring maintenance. Periodic changes of batteries subject both the animal and the experimenter to some risk and disturb the behavior under study. To circumvent this we have designed a unit which generates its own power. The unit, which measures 3 by 6 by 7 cm and weighs 200 g, is mounted directly on the animal's head (*1*). The upper surface of the unit contains an array of 40 solar cells which, when exposed to natural or artificial light, continuously recharge small nickel-cadmium batteries of 50 ma-hr capacity. These batteries provide uniform power during any dimming of the incident light caused by head movement or shadows. Figure 1 illustrates the power available from this 12-v supply under various light intensities. The power consumed by the stimulator consists almost entirely of a steady "keep-alive" current of 0.12 ma plus an additional 0.6 ma during periods of use. The figure also shows the time required to recharge the batteries under various light intensities after 1 hour of continuous use and includes a safety factor of 35 percent. Since the stimulator operates properly until the batteries are 25 percent exhausted, longer stimulation periods are possible if more time is allowed for recharging.

A frequency-modulated carrier (130 to 140 Mc/sec) from the transmitter is received by a solid-state, superheterodyne receiver (Fig. 2) stabilized by means of a crystal. The sensitivity of the receiver, −35 db, was purposely designed to be low so as to minimize interference from extraneous radio-frequency fields. The receiver is conventional with the exception that the RF, mixer, and oscillator stages are operated in cascade with respect to the power supply to conserve current. The limiter is regulated by voltage. Stimulation pulses, on the one hand, cause the carrier to deviate in a positive direction and send output pulses into the current-regulator circuits. Channel selection pulses, on the other hand, cause the carrier to deviate in a negative direction and send pulses into the channel selection circuits. In this manner, almost complete separation between channel selection pulses and stimulation pulses is effected.

Remote selection of any one of 11 stimulating electrodes in each animal is accomplished by a specially designed, miniature (28 g) stepping switch. There

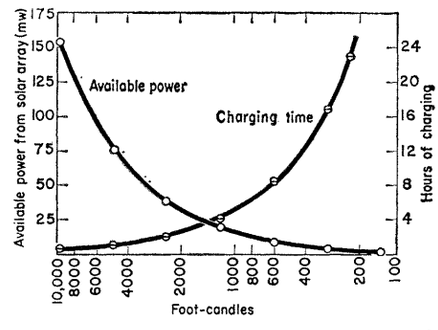

Fig. 1. Graph of power availability and of charging time after 1 hour of use under various light intensities. One foot-candle is equivalent to 11 lumens per square meter.