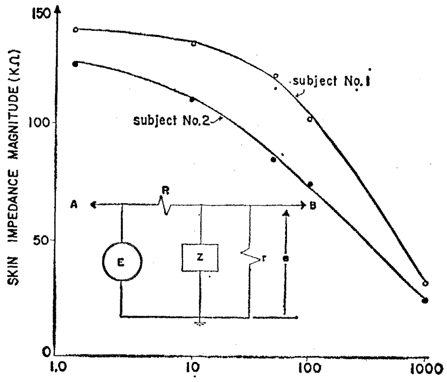

Fig. 1. The magnitude of impedance of the skin as a function of frequency, and a schematic diagram of the apparatus for measuring skin impedance (inset). Points A and B are connected to the horizontal and vertical inputs, respectively, of an oscilloscope. The remaining symbols are explained in the text.

range of 1 to 1000 cy/sec is most important for research on galvanic skin response, since higher frequencies have been reported (*3*) as measuring general dielectric characteristics of body tissue and not the properties of skin alone. The purpose of the present research was to determine phase angles and impedances of human skin as a function of frequency over the range of 1 to 1000 cy/sec. The current densities were also varied.

The output of a model M2-Southwestern Industrial Electronics audio oscillator was connected through a high resistance to the skin of the subject and from there to the vertical plates of a model 502 Tektronix oscilloscope (Fig. 1, inset). The sine wave output from the oscillator was connected directly to the horizontal plates of the oscilloscope. A Lissajous figure was obtained in which the degree

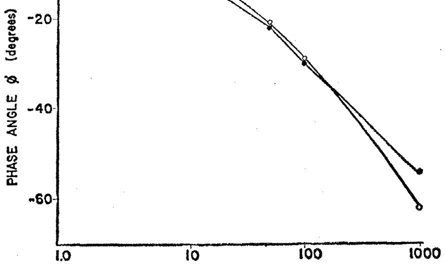

Fig. 2. Phase angle as a function of frequency.

of ellipticity was related to the electrical capacity of the skin. The complex skin impedance, Z, was computed from the following formula: $Z = eR_p/(E' - e)$, where $R_p = Rr/(R + r)$ and $E' = Er/(R + r)$. The oscillator voltage E, the voltage developed across the skin e, and their relative phase angle were read from the Lissajous figure. The input resistance, r, of the oscilloscope was 1 megohm. The series resistance, R, was 0.5, 1, or 2 megohms. The current passing through the subject's skin was given by $i = (E' - e)/R_p$, as is evident from the relation $e = iZ$. The symbols Z, e, E', and i are complex numbers whose magnitudes and phase angles are functions of frequency. The formulas for Z and i result from straightforward passive-network analysis of the circuit in the inset of Fig. 1.

Two subjects were tested over five frequencies, 1, 10, 50, 100, and 1000 cy/sec, in ascending and descending order. Three levels of current, ranging from approximately 14 to 62 μa, were studied in ascending and descending order.

Medcraft circular silver electroencephalograph electrodes, 1.0 cm in diameter, were taped tightly to the pads of the second and fourth fingers of the left hand. No artifacts resulted from movement of the fingers or hand. The electrodes were used "dry," without external pastes, to avoid some of the problems described by Montague (*4*) and by Edelberg and Burch (*5*). These authors found that basal skin resistance depends greatly upon the type and concentration of electrode paste used. However, it is known from the work of Stoughton (*6*) and Griesemer (*7*) that no electrode is truly dry because a surface layer of emulsified material is always present on the skin and provides some sort of natural fluid medium.

Figure 1 presents the mean impedance for each of the two subjects and clearly shows the marked influence of frequency on this measure. At 1000 cy/sec the impedance drops to approximately 20 percent of its value at 1 cy/sec. Over the same range the phase shift, ϕ, changes from about -2 degrees to -58 degrees (Fig. 2). It is interesting to note that the two subjects have similar phase angles but relatively more discrepant impedances. This suggests that phase angle may be a more useful measure than impedance, because individual differences in base level are reduced to a minimum.

The magnitude of the impedance and the phase angle were invariant with changes in the level of current, in the range used. This implies that current variation need not be considered as a source of error and that the skin acts as a linear system to impressed a-c voltage. In contrast, Davis (*8*) and Grings (*2*) have shown that current does affect base resistance, or galvanic skin response, when a d-c system is used, although these authors studied a wider range of currents.

In summary, it appears probable that the use of low-frequency a-c sine wave inputs avoids some of the artifacts often associated with research on galvanic skin response, and provides, at the same time, unequivocal measures of certain electrical characteristics of the skin.

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21 May 1963

Startle Reaction: Modification by Background Acoustic Stimulation

Abstract. *Six rats were exposed to a sequence of gunshot-like acoustical bursts during silence, during steady noise, and during pulsed noise. Assessment of their startle reactions to the bursts revealed that a background of steady noise enhanced the response, whereas a background of pulsed noise produced suppression of response. It is hypothesized that pulsed noise causes a relative refractory state in the mechanisms responsible for startle and that steady noise may enhance startle by masking uncontrolled punctiform acoustic stimuli.*

When a sudden intense sound is presented to a member of the class Mammalia, the immediate response often consists of an abrupt reflexive movement of the entire body. Landis and Hunt (*1*) used high-speed cinemaphotographic techniques to study this reaction (the primary startle pattern) and reported only slight variations in response topography among individuals and across species. Recently we began to investigate the psychophysics of acoustically produced startle in the rat, using an instrument designed to measure the ballistic-type movement which characterizes the response. In the course of doing so, however, we noticed that the tendency to respond appeared to be extremely sensitive to the presence or absence of only moderately intense background noise. Our purpose in the present experiment was to examine this phenomenon.

The device for the assessment of startle has been described elsewhere (*2*). Briefly, it consists of a small, plexiglass animal chamber, 3 by 3 by 8 inches (7.6 by 7.6 by 20.3 cm) with a stainless-steel grid floor. The chamber is supported from above and below by heavy compression springs attached to a rigid metal superstructure. Connected to the bottom of the chamber is a magnet which rides in an electrical coil. Movements of the chamber move the magnet in the coil and produce an electrical current which is amplified, rectified, and then passed to an Esterline-Angus recording milliammeter. Because the output of the system is proportional to the *rate* at which magnetic lines of flux cross the coil, the device is highly sensitive to the sudden ballistic-type movement involved in startle, but is relatively insensitive to the gross, but more or less slow, movements involved in general activity. The entire assembly —animal chamber, superstructure, magnet, and coil—were mounted within a commercially produced icebox to provide a measure of acoustic isolation. A one-way-vision window was fitted to the door of the icebox to permit visual observation. The acoustical burst which served as a stimulus for the startle reflex was produced by discharging a condenser (100 mf charged to 450 volts) through the voice coil of a 5-inch (12.7 cm) Utah speaker mounted within the icebox. Background stimulation was presented through a second speaker which was also mounted within the icebox. It consisted of thermal white noise that was passed through a Grason-Stadler electronic switch and amplified before being fed to the subject. When assessed on the C scale of a General Radio sound-survey meter placed within the animal's chamber, the ambient noise level yielded an average reading of 58 db with occasional peaks as high as 72 db (sound pressure level relative to 2×10^{-4} dyne/cm^2). The background noise yielded a steady reading of 85 db, whereas the startle stimulus yielded a reading of 110 db. It should be noted, however, that the sound-survey meter is not designed to assess the momentary intensity of explosive sounds and hence that the intensity of the burst is probably much greater than the estimate provided by this instrument.

The subjects were six male Wistar rats that were approximately 150 days old. Each animal was exposed to a series of 100 acoustical bursts spaced 10 seconds apart. The treatments consisted of modifying the background stimulation during the series. There were three conditions of background stimulation: (i) ambient level of acoustic stimulation (hereafter referred to as silence for purposes of convenience), (ii) steady noise, and (iii) interrupted noise. The duty cycle of the noise during condition iii was 0.5 second on and 0.5 second off, and during this condition, as well as during condition ii, the rise and decay time for the noise was always 10 msec. The order of treatments varied from one subject to another, but all subjects were exposed to each treatment three times. Five minutes after a subject was placed in the chamber, the series of acoustical bursts began. For all subjects the first ten bursts occurred during silence; then during each of the subsequent nine blocks of ten trials, one or another of the three treatments occurred. The order of treatments was selected from a set of Latin squares, so that for a given subject, all three treatments occurred during each sequence of 30 trials and each treatment appeared once

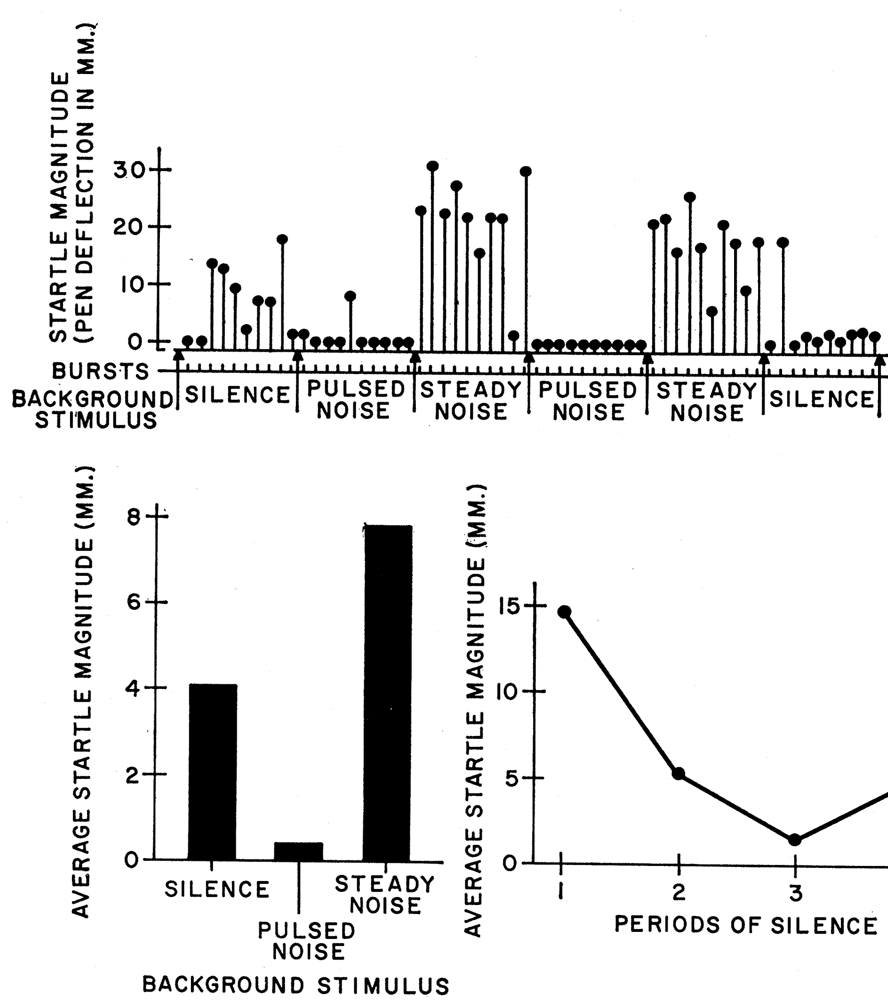

Fig. 1. The effect of background stimulation on the startle reaction to an intense sound. The top half shows a segment of the record from a single animal. The overall effects of background stimulation are summarized for all subjects in the bar graph. The curve to the right shows the effects of repeated presentation of the intense sound during the four periods of silence.

in each of the three possible positions within the sequence.

The top half of Fig. 1 provides a schematic representation of one segment of the record produced by a single rat (animal No. 3). It illustrates the sizeable changes in startle reaction to the bursts that are produced by steady and pulsed background acoustical stimulation. Pulsed noise all but eliminated the startle reaction, whereas steady noise caused a marked increase in response magnitude. The bar graph in the lower left-hand corner of Fig. 1 summarizes the data from all subjects. It shows the average magnitude of startle during the final nine blocks of ten stimuli. In this period, each treatment occurred three times. The overall effect of variation in background stimulation was sizeable. Pulsed noise suppressed the startle reflex and steady noise enhanced it. An analysis of variance yielded a significant effect of treatments ($F = 10.90$, degrees of freedom = 3 and 40, $p \leqq .01$). The three replications, however, did not differ significantly, nor was there a significant interaction between treatments and replications. Thus, it is concluded that although the effects of the treatments were large, their effects were limited to the periods in which they occurred.

Some adaptation of the startle response was revealed when responses in the first ten trials (prior to the initiation of the treatments) were compared to the responses during the three subsequent silent periods. The average magnitude of startle reaction across all subjects during each of the four silent periods is presented in the lower right-hand graph of Fig. 1. An analysis of variance yielded a significant effect of periods ($F = 11.95$, degrees of freedom = 3 and 15, $p \leqq .01$), but the previous nonsignificant effect of replications and an examination of Fig. 1 suggest that such adaptation as occurred was essentially complete by the end of the first period.

The finding that steady noise enhanced startle makes it clear that the suppression of startle produced by pulsed noise is not a simple masking phenomenon. Nor, for that matter, is it due to a fixed temporal relationship between the pulses and the startle stimuli. Background stimulation was initiated and terminated by hand, and for this reason the phase relationship between the background pulses and the acoustic bursts varied from one treatment condition to the next. Observation of the subject throughout testing and a subsequent examination of their records also made it clear that the pulsed noise and the steady noise never produced an overt startle reaction.

We wondered whether the effects of the background stimulus were unique to the auditory modality. In order to examine this question, several rats were run through the procedures of this experiment with the modification that the background stimulation was provided by a 100-watt light bulb. No effects on startle to the acoustic burst were observed when the background stimulus was on, off, or flashing. Thus, at present, there is no evidence that these effects extend beyond the auditory modality.

Obviously, attempts at an explanation must be speculative. It does, however, seem likely that the punctiform stimulation provided by the pulses of noise caused a partial activation of the mechanisms responsible for startle and because of the high repetition rate (one per second) they also produced a relative refractory state. If this were so, the facilitating effect of steady noise might reflect the masking of punctiform acoustic stimulation provided by the animal's movements and by random fluctuations in the ambient level. Further research which provides better acoustic isolation and which examines the effects of pulse rate, rise time, and intensity of background stimulation may help to clarify the issue. Regardless of the ultimate explanation, however, it is apparent that these results may have certain practical ramifications. There are times when a startle reaction is particularly undesirable, for example, during the performance of a precision task (*3*). If the present results are applicable to humans, the use of low-level pulsed noise may provide a convenient and effective technique for reducing the chances that a sudden intense sound will produce startle and disrupt the task (*4*).

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Pulmonary Edema as a Consequence of Hypothalamic Lesions in Rats

Abstract. *Rats were observed for the incidence of pulmonary edema after the placement of hypothalamic lesions by radio frequency thermocoagulation or d-c electrolysis. In the animals with electrolytic lesions, 31 percent died with pulmonary edema and marked signs were observed in another 20 percent. Moderate transient signs appeared in only 3.7 percent of the animals with radio-frequency lesions, and there were no deaths attributable to this syndrome in this group. These results suggest that this syndrome is an irritative consequence of the electrolytic lesion process rather than a "release" phenomenon.*

One of the hazards of experimental destruction of regions in the hypothalamus by electrolytic lesions is a relatively high mortality rate. Pulmonary edema with its complications is presumably a major factor in such cases. This phenomenon has been studied experimentally in rats by Patton and his co-workers (*1, 2*). Immediately postoperatively there may be a brief period of apparent normality. This is typically followed by a phase of hyperactivity and "forced progression." Subsequent to this the animal begins to exude a froth, usually flecked with blood, from its nose and mouth. It begins to gasp and assumes a posture similar to opisthotonus, with its head thrown back and its forelimbs extended. Minimal stimulation at this stage will precipitate convulsive seizures. Death normally follows soon after. On autopsy the lungs are found to be greatly distended and deep red in color. Histological examination of the lung tissue shows severe hemorrhage and edema with distention of the alveoli and perivascular spaces with erythrocytes and fluid.

In a previous study (*3*), I showed that the signs of hypothalamic hyperphagia usually associated with electrolytic lesions in the ventromedial region of the hypothalamus failed to appear when the lesions were produced by radio-frequency thermocoagulation. I suggested that the effects of the electrolytic lesions were due to irritation rather than simple tissue removal. Because the number of animals involved in that study was relatively small, a subsequent investigation was