Effects of acoustic rise time on heart rate response[1]

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Effects of acoustic rise time on heart-rate (HR) response were tested in two experiments. With 50- and 75-dB tones, effects were not clear-cut, but, at 90 dB, fast onsets produced an initial acceleration and slow onsets an initial deceleration. Results were discussed in terms of orienting and startle responses.

Russian work on orienting has stimulated interest in the unconditioned responses to simple, sensory stimuli. After reviewing the relevant literature on heart-rate (HR) responses, Graham & Clifton (1966) hypothesized that HR deceleration should occur if conditions were appropriate for eliciting orienting and HR acceleration should occur if stimulus intensity were high enough to elicit what Sokolov (1963) has called a "defensive reflex." Although the empirical data offered considerable support for the hypothesis, there were some reports of a diphasic response of acceleration-deceleration in situations that might be expected to produce orienting, i.e., where stimulation was novel but below pain threshold. Graham and Clifton suggested that the initial acceleration might be a partial defensive reflex, since stimulus intensities were in Sokolov's "pre-pain zone," or, alternatively, the acceleration might be due to startle, evoked by the characteristics of stimulus onset. Startle was suggested by the observation that common methods of delivering stimuli produce sudden, "noisy" onsets, that such onset characteristics are the effective stimulus for startle when stimulus intensity is sufficiently high, and that startle and HR acceleration are associated.

The majority of HR studies have used acoustic stimuli and have not attempted precise control of stimulus onset. The usual method is to deliver the stimuli by means of relays or mechanical switches. Since the full amplitude signal is thus applied instantaneously to the speaker, a transient or series of transients occur that can be heard as a click. Whether or not this is sufficient to produce startle probably depends upon stimulus intensity, the amount of contact "bounce," characteristics of the speaker, and other factors difficult to specify or control. By switching electronically, contact bounce is eliminated and the rate of rise of a stimulus can be manipulated.

Fleshler (1965) used electronic switching to study the effect of rise time on behavioral startle in the rat. He found that the effective stimulus was a sufficiently high intensity of stimulation reached within a sufficiently short time (12 msec). On the assumption that HR acceleration and behavioral startle are associated, Fleshler's results suggest that, below some intensity level, rise time should not affect the HR response, even with a sudden onset, while above the critical intensity level, initial HR acceleration would occur with rapid rise time but not with slow rise time. Presumably, later HR changes would depend upon the asymptotic intensity. If intensity were low enough to elicit HR deceleration when onset was gradual, then deceleration should still occur following the initial acceleration evoked by rapid onset.

To investigate rise time-intensity effects on HR responses, two experiments were conducted. In the first, a 1,000-Hz tone rose gradually or rapidly to peak intensity of 50 or 75 dB. Previous work suggested that tones below about 60 dB should produce solely decelerative responses on initial trials, whether or not onsets were gradual (Graham & Clifton, 1966). A 75-dB stimulus was selected, since this was close to the lowest intensity at which a diphasic response had been reported in earlier work. However, rapid rise time did not produce a clear effect in the first experiment, and the second experiment, therefore, presented tones of 50 and 90 dB, again with slow and rapid onsets. In both experiments, there were only four presentations of each stimulus, interspersed with presentations of the other three stimuli. Because the orienting response habituates rapidly in adults and may be replaced on later trials by a defensive reflex, responses averaged over more than the first few presentations of a stimulus do not unequivocally indicate orienting (Sokolov, 1963).

SUBJECTS

In fulfillment of a course requirement, 48 male undergraduates served as Ss, 24 in each experiment. Twenty-four additional Ss were not retained due to procedural errors or equipment failure (18), cardiac or respiratory symptoms (2), movement artifacts (3), and unreported difficulty (1).

APPARATUS

The Ss were tested in an air-conditioned, IAC Model 1203A, sound-attenuated chamber, and recording and stimulus-generating equipment was located outside the chamber. Stimuli, produced by an HP 200 CDR wide-range oscillator, were delivered through an Acoustic Research 2ax speaker placed 3 ft in front of the S's head. Intensity and temporal characteristics of stimuli were controlled, respectively, by an HP 350C attenuator and by an Iconix 6010 and 6255 preset and clock/counter. Stimulus intensity was measured at the site of the S's head by a General Radio sound-level meter set on the A scale. Background noise level, measured in the same way, was less than 24 dB. Rise and fall time were controlled by a Wisconsin electronic switch that produces a trapezoidal envelope (Olson & Ludwig, 1965).

The stimulus artifact and the output of a Type 9851 cardiotachometer were recorded on an Offner Type R dynograph. In the case of 36 Ss, shaped pulses coincident with stimulus onset and with each cardiac R-wave were also tape-recorded on a Model 1028 Magnechord. Polygraph records were hand-read with an error of ±6 msec per R-R interval; taped data were read by a LINC computer, with an error of ±992 microsec. Respiratory activity was also monitored but was not analyzed.

PROCEDURE

The S was seated upright in a comfortable armchair in the sound chamber. Beckman biopotential electrodes were attached in a standard Lead II placement, and a mercury strain gauge was taped across the chest. To reduce the possibility of drowsiness, chamber lights were kept on and the first stimulus was usually presented within 2 min after the chamber door was closed.

Each S received 16 presentations of a 2-sec, 1,000-Hz tone at 45-sec intervals from tone offset to onset. Two levels of stimulus intensity were factorially combined with slow (S) and fast (F) rates of rise to yield four stimulus types: In Experiment 1, intensities were 50 or 75 dB and rise time was 300 or 3 msec; in Experiment 2, values were 50 or 90 dB and 300 msec or less than 5 microsec. The four stimulus types were presented in a block that was repeated four times. Order of stimuli within blocks was balanced across Ss within each experiment.

Cardiac intervals were measured continuously from 1 sec preceding to 19 sec following stimulus onset and were converted to average rate in bpm for each of the 20 sec. The average for a given second included all full and partial beats within that 1-sec interval, weighted according to the fraction of the interval occupied by each. Data from the four presentations of like stimuli were averaged. To facilitate comparison, per-second HR values were expressed as differences

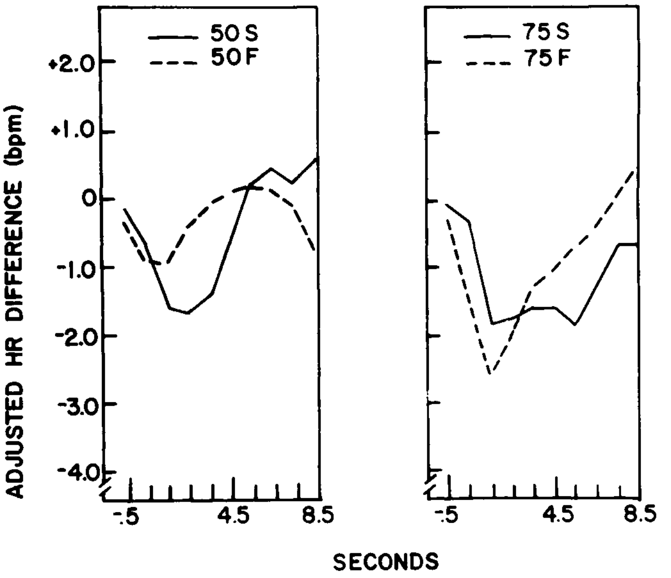

Fig. 1. Second-by-second HR response to four presentations of 1,000-Hz tones of 50 and 75 dB and 300-msec (S) or 3-msec (F) rise time.

adjusted for regression on prestimulus HR.[3] Adjustment used the regression equation determined from both experiments since per-second, per-trial regressions were homogeneous both within experiments [overall F(319,7040), Experiment 1 = 1.06, Experiment 2 = 0.92] and between experiments (F = 1.10). Mean prestimulus levels were 74.6 bpm in Experiment 1 and 76.8 bpm in Experiment 2.

RESULTS

The rise time effect was not clearly demonstrated in Experiment 1. As Fig. 1 shows, initial HR change was decelerative with all stimuli and, with the exception of 50F, was significantly below prestimulus for several seconds, as tested by t ratios. Fast rates of rise did lead to briefer periods of deceleration and an earlier, rapid acceleration. This effect was tested by analyses of the variance in orthogonal components of trend across the first and second 10-sec periods. Error terms were based on the variance in the respective trends, linear through quartic, of individual Ss, and df were, therefore, 1 and 23 for all Fs reported. The more prolonged period of deceleration with slowly rising stimuli was reflected in a significant difference, due to rise time, in the quadratic trend across the first 10 sec ($F = 5.06$, $p < .05$). Intensity difference also produced a significant effect on the quadratic trend and interacted with rise time to affect the linear trend. The only effect during the second 10-sec period was higher average HR with fast rates of rise ($F = 5.16$, $p < .05$).

Rise time did have the expected effect in Experiment 2 (Fig. 2). There was immediate deceleration to the 50-dB stimulus, whether or not the rise was gradual, but the 90-dB stimulus evoked immediate deceleration when rate of rise was gradual and immediate acceleration when rate of rise was rapid. Although the decelerations differed significantly from prestimulus, as tested by per-second t ratios, the accelerative phase did not. Trend analyses confirmed the Intensity by Rise Time interaction (cubic 10-sec $F = 13.0$, $p < .005$) and indicated that it was due primarily to differences between 90S and 90F during the first 5 sec (Intensity by Rise Time quadratic 5-sec $F = 10.2$, $p < .005$; 90S vs 90F, 5-sec $F = 4.46$, $df = 4.92$, $p < .01$; 50S vs 50F, 5-sec $F = 1.07$). There were no significant rise time effects during Seconds 5 to 9 or Seconds 10 to 19, in contrast to intensity effects that did persist.

DISCUSSION

Two findings of interest were obtained in these experiments. First, the predicted rise time effect was found with a 90-dB stimulus. The initial HR response was an acceleration when rise time was rapid and a deceleration when rise time was low. Second, the initial response was decelerative, with both rapid and slow rise time, when stimulus intensity was 50 or 75 dB. The consistent occurrence of initial deceleration under these circumstances, i.e., in response to the first few presentations of low to moderately intense, simple, sensory stimuli, adds support to the hypothesis that deceleration is the cardiac component of orienting.

The possibility of a rise time effect was originally proposed by Graham & Clifton (1966) as one explanation of the diphasic response sometimes found at intensities of 70 dB or higher. They suggested that the initial acceleration might be part of a startle reflex due to stimulus onset characteristics. This conception implies that onset and steady-state characteristics of a stimulus may elicit distinguishable HR responses. It is a commonplace in neurophysiology that responses to transient change of stimulation differ from responses to enduring characteristics. It would not necessarily follow that HR responses show the same phenomenon, but there is evidence, at least, that motor

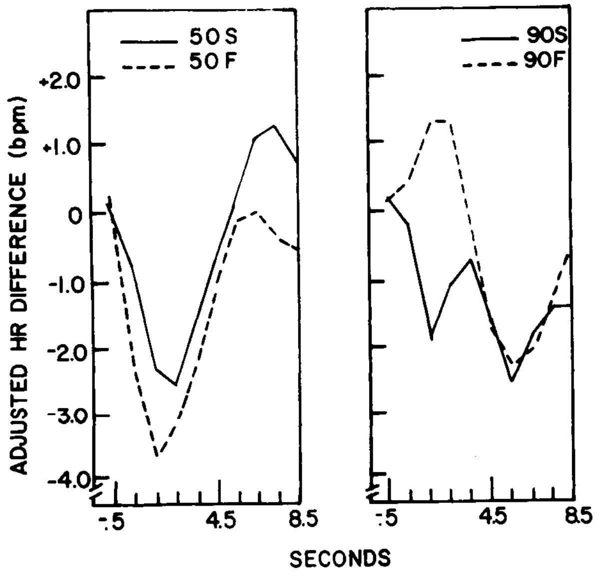

Fig. 2. Second-by-second HR response to four presentations of 1,000-Hz tones of 50 and 90 dB and 300-msec (S) or < 5-microsec (F) rise time.

startle responses to acoustic stimuli are determined by onset characteristics (Fleshler, 1965), and that they are mediated by different mechanisms, both centrally and peripherally, than are other responses to sound. Szabo & Hazafi (1965) have shown that relatively confined lower brain-stem lesions that abolish the acoustic startle reflex leave intact orienting movements to sound. Peripherally, also, it is well established that there are "protective" middle ear reflexes, sensitive to high intensity and abrupt onset (Loeb, 1964), that are distinct from the mechanisms that code stimulus information. The tensor tympani response, in particular, has been associated with the startle reflex (Klockhoff, 1961). It is not unreasonable, therefore, to entertain the hypothesis that there may be corresponding and distinguishable HR responses. The present results offer support for the hypothesis.

While the present data demonstrate that rise time can affect the initial phase of HR change if stimulus intensity is high enough, the results at lower intensities cannot be unambiguously interpreted. The shorter latency of acceleration in Experiment 1 is consonant with the hypothesis of a weak startle effect interacting with a strong orienting response. However, it is not clear why rapid rise time should have any effect as late as Seconds 10-19, nor is there any explanation of the inconsistent effects of rise time at 50 dB.

A parallel experiment with 4-month-old awake and sleeping infants (Berg, Berg, & Graham[4]) also obtained equivocal results at 50 dB. Depending on how precisely the awake state was defined, rapid rise time produced either a slightly longer or slightly shorter deceleration at 50 dB. At 75 dB, however, the decelerative phase was consistently shorter and the accelerative return occurred earlier. There was no acceleration in the second 10-sec period. The most interesting finding of the study was an interaction of rise time and sleep-wake state. With sleepy Ss, rise time had a greater effect. Rapid onsets produced steep and large accelerations, at both 50 and 75 dB, while gradual onsets produced a period of deceleration and a more gradual and smaller phase of acceleration.

The findings therefore indicate that rapid rise time can produce a "startle" response of HR acceleration if stimulus intensity is 90 dB in waking Ss and considerably lower than that in sleeping infants. It is possible that a startle effect can also account for diphasic responses reported in previous adult studies, even at intensities as low as 70 dB, if state is taken into account or onset characteristics, other than rise time, are considered. Rudolph (1965) used a 75-dB taped rectangular pulse, with onset controlled by Hunter timers. The resulting signal, viewed on an oscilloscope by the present authors, showed large, high-intensity transients at onset. Transients were also observed when a 75-dB, 1,000-Hz tone was controlled by relays. The persistence of transient activity varied with the relay and speaker tested. Even with the shortest rise time of the present experiment, no transients were visible, although a click was just audible at 3-msec rise time.

Although intensity differences produced significant effects in both experiments, they have no clear bearing on the theoretical questions at issue. According to Graham & Clifton (1966), a nonmonotonic relation would be expected, i.e., as intensity increased from low to moderate, deceleration should first increase and then, at still higher intensities, should lessen and shift to acceleration. Difference in response to 50 dB in the two present experiments makes it impossible to pool results across experiments and, obviously, no conclusions can be drawn about a nonmonotonic function when only two intensities are tested within an experiment. It is possible that contrast effects may account for the between-experiment difference at 50 dB.

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NOTES

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3. Adjustment does not affect response trends since it only lowers or raises the curve as a whole without changing the relationship of the parts (Chase, Graham, & Graham, 1968).

4. Berg, K. M., Berg, W. K., & Graham, F. K. Infant heart rate response as a function of stimulus and state. Unpublished manuscript, 1970.