

## Cardiac Activity Preparatory to Overt and Covert Behavior

**Abstract.** *The heart rates of 17 women subjects were recorded as they prepared to make both overt (key press) and covert (silently thinking the word "stop") responses. A very reliable preparatory cardiac response was obtained regardless of whether the overt or covert response mode was employed. The temporal development of this cardiac response faithfully reflected the speed with which the subjects were asked to respond, suggesting that in the covert condition heart rate could be used to detect the time at which a mental event was being generated.*

Covert activity is, by definition, inferred because it cannot be (or has not been) directly observed or measured. For example, the generation of specific thought sequences such as "counting in one's head" would be so classified since at this time there is no direct procedure for measuring such activity. However, even at the simplest level, it has been shown that discrete thoughts can act as stimuli for autonomic responses (1). It would logically seem to follow that the process of generating such covert activity may possess identifiable response characteristics as well. We report here that the shape of the cardiac waveform in preparation for making a simple response provides an accurate indication of the time at which the response is being generated, even when the behavior is entirely covert.

Twenty women subjects between the ages of 21 and 30 were secured by advertisements in local newspapers. Upon entering the laboratory all subjects were seated in a sound- and temperature-controlled room whereupon standard electrocardiographic plate electrodes were attached. A cardiota-

chometer (Lexington Instruments model 107) was used to provide a continuous measure of the subjects' heart rates (in beats per minute). The heart rate data and appropriate coding signals were recorded on a frequency-modulated (FM) tape recorder (Sanborn-Ampex model 2000) in addition to being visually monitored on a polygraph (Offner type R dynagraph). Logic modules (Grason-Stadler) were used for programming display lights and for measuring response latencies.

The covert response we selected was to have the subjects silently think to themselves the word "stop"; a simple key press served as the overt response. Since Lacey and others (2) have shown that variations in response speed tend to be associated with changes in the preparatory cardiac response (faster responses are accompanied by greater decelerations of the heart), we further compared the autonomic similarity of overt and covert responses by also manipulating the speed with which they were executed. The subjects were instructed to perform half of their (overt and covert) responses "as fast as possi-

ble" after the offset of a 5-second warning light; on the remaining trials light offset served as a signal to respond "deliberately slow." A short break after every ten trials was the signal for the subjects to switch from the motor to the mental mode or vice versa. Within each such block of trials the subjects were simply asked to alternate their fast and slow responses. These instructions were supplemented by the use of indicator lights labeled "fast," "slow," "think," and "push." This arrangement ensured that the subjects were always informed about the nature of the upcoming response. A total of 40 such trials were programed with the inter-trial interval ranging from 20 to 30 seconds. Counterbalancing was achieved by having half the subjects respond in the motor mode in blocks I and III and in the mental mode in blocks II and IV; for the remaining subjects the order was reversed. Within each of these subgroups, half the subjects responded fast on the even trials; the other half responded fast on the odd trials. Finally, the subjects were urged to make their motor and mental responses as equivalent as possible—especially on the slow trials where specific qualifiers such as "deliberately slow . . . about a half second after light offset . . . in a leisurely manner" were used for this purpose. After reading the instructions, the experimenter demonstrated the use of the response key and then administered a few practice trials to ensure that the instructions were fully understood.

Each subject's averaged cardiac response ( $N = 10$ ) under the four conditions of the experiment was obtained by playing the FM tape into a signal averager (Fabritek model 100). The data-averaging epoch included 17 seconds of the heart rate record, beginning 3 seconds prior to light onset to allow for an estimate of the pretrial, or "base" heart rate. A sampling rate of 7.5 samples per second (real time) was employed. We retained permanent records of these averaged responses by using the polygraph as a visual readout device while simultaneously rerecording the averages on a second FM tape. The averaged responses of 17 subjects (3) were then selected from this tape and averaged to obtain group curves that were plotted on an X-Y recorder (Hewlett-Packard).

Figure 1 presents the computer-averaged cardiac responses of the entire group as a function of which one of the four responses was about to be

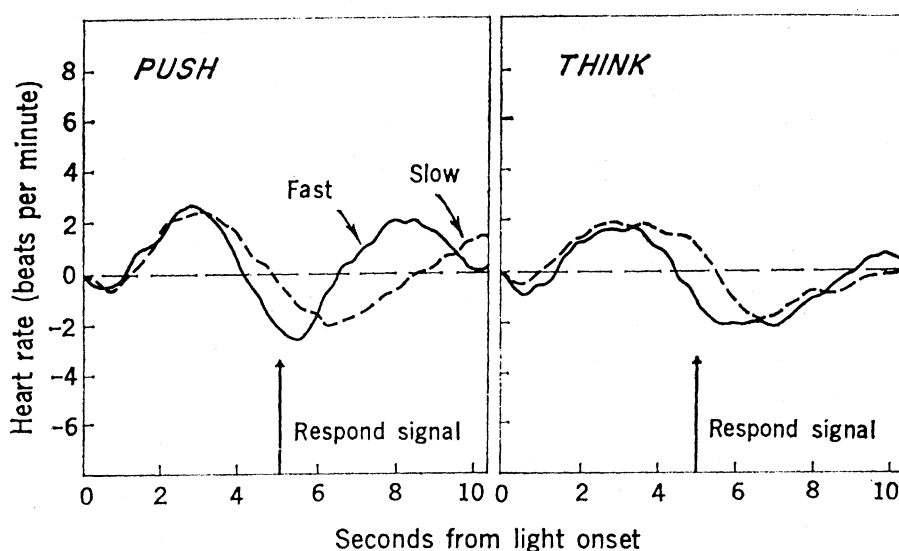


Fig. 1. Computer-averaged heart rate responses as a function of response mode ("push" or "think") and speed ("fast" or "slow"). Plots are in the form of difference scores relative to the basic measure. The waveform was moved back in time 0.75 second to correct for cardiota-

executed (4). As can be seen in Fig. 1, whether motor or mental, fast or slow, the waveforms are all qualitatively very similar, having as their two main components an early cardiac acceleration followed in turn by a deceleration. However, the major quantitative difference is that as early as 3 seconds into the warning interval, the cardiac decelerations for both response modes were already beginning to target themselves toward different points in time as a function of the speed of the intended (but not yet performed) response—that is, fast or slow (5).

We performed statistical analyses on the various response components seen in Fig. 1 by obtaining the following measures of each subject's computer-averaged response: (i) the highest heart rate value between second 1 and second 4 (accelerative peak) and its exact time of occurrence; (ii) the lowest heart rate value between second 4 and second 8 (decelerative peak) and its time of occurrence; (iii) the highest heart rate value after second 8 (recovery peak) and its time of occurrence. Figure 2 summarizes the mean values for these three amplitude measures and their times of occurrence as a function of response conditions. Again the similarity between overt and covert responses is striking, whereas the temporal heart rate phasing differences as a function of response speed are clearly evident for both the mental and motor mode. Separate two-way (speed by mode) repeated measure analyses of variance (6) conducted on all six (amplitude and time) measures of the waveform demonstrated that (i) the fast-slow phasing differences were highly reliable for the deceleration and recovery components ( $P < .001$  for both), but not for the earlier acceleration; (ii) there was no difference in the magnitude of this forward shift between the overt and covert responses; and (iii) the slight amplitude enhancement of the various components manifest under the motor condition was not statistically significant.

Examination of the behavioral data provides evidence that the observed shifts in the cardiac waveform represent more than a simple tendency toward more sluggish cardiac responding when subjects are not motivated to respond quickly. As measured between the fast and slow motor conditions, the mean forward shift of 1.01 seconds observed for the time of decelerative peaking corresponds almost exactly to the 1.03-second mean lag in the sub-

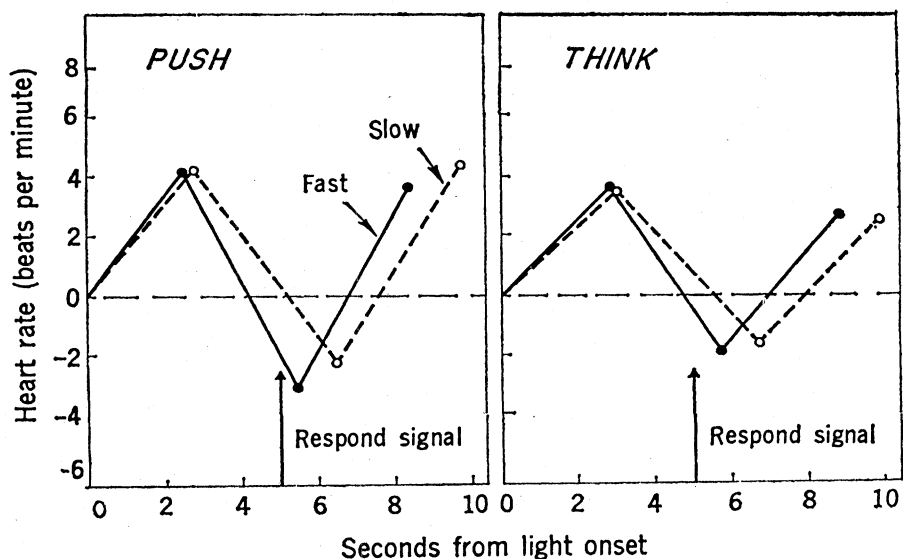


Fig. 2. Bivariate plot of the amplitude and time of occurrence of the three components of the cardiac waveform (see text) as a function of response mode ("push" or "think") and speed ("fast" or "slow"). Plots are in the form of difference scores relative to the base measure. The waveform was moved back in time 0.75 second to correct for cardiachometer lag (warning stimulus onset at  $t = 0$  second, offset at  $t = 5$  seconds).

jects' actual key-pressing behavior. Further analysis of individual subjects revealed that this overall group tracking phenomenon was not a serendipitous finding. A correlational analysis demonstrated that the extent of the decelerative shift in heart rate was directly related to the length of time a given subject waited to press the button in the slow relative to the fast condition ( $r = +.51$ ,  $P < .025$ ). Although the strength of this relationship suggests that other influences were also operating on heart rate, the obtained regression parameters of 0.06 second for the Y (or "extent of the decelerative shift") intercept, and 0.91 for the slope suggest that, in spite of the "noise," the underlying relationship between heart rate and behavior reflects an extremely precise temporal tracking phenomenon. Although we obviously could not obtain latency measures for the covert responses, the data here are also suggestive since the subjects were instructed to make these fast and slow responses as equivalent to the motor responses as possible. Correspondingly, the covert decelerative shift was quite comparable to that observed when the motor responses were employed, being just 0.08 second shorter.

It seems reasonable to conclude that covert events can meaningfully be preceded by autonomic responses, the specific form of which can depend upon the same task variables as seen for motor responses—for example, the fast-slow variable of the present experiment. As such, these data support

Sperry's notion (7) concerning the controlling significance of conscious activity on brain processes as well as the recent attempts by Cautela (8) to treat emotional and behavioral problems by means of covert procedures. In summary, the data presented here indicate that the actual activation of the musculature and its efferent outflow resulting in overt behavior is not a necessary prerequisite for autonomic responding (9); rather, antecedent central processes (for example, attention, plans) can themselves be sufficient conditions for obtaining autonomic involvement preparatory to behavior (10).

GARY E. SCHWARTZ

J. DAVID HIGGINS

Harvard Medical School, Massachusetts  
Mental Health Center, Boston 02115

#### References and Notes

1. In this report terms such as "thought" and "mental event" are used simply for convenience to refer to those specific brain processes that can be self-generated, consciously monitored, and verbally reported by a subject. Although it has long been assumed (for example, in psychosomatic medicine) that such mental events per se may have autonomic counterparts, only recently has this phenomenon been empirically validated by means of specially designed experimental psychophysiological procedures; see G. E. Schwartz, *Psychophysiology*, in press.
2. J. I. Lacey, in *Psychological Stress*, M. H. Appley and R. Trumbull, Eds. (Appleton-Century-Crofts, New York, 1967), p. 14; P. A. Obrist, R. A. Webb, J. R. Sutterer, J. L. Howard, *Psychophysiology* 6, 695 (1970).
3. Three subjects had to be excluded because of respiratory irregularities or failure to follow instructions, or both. For the remaining subjects, the evidence of respiratory irregularities was so infrequent that it was possible to remove these trials from the average.
4. Variability among pretrial heart rates for the four conditions was practically nonexistent despite subjects' knowledge of the nature of the upcoming trial. In no case did any of

- these means differ from the grand mean of 76.78 by more than 0.5 beat per minute.
5. Separate averaging as a function of the counterbalancing procedure indicated that the general trends of Fig. 1 were equally manifest regardless of whether the subjects began the experiment by using the covert (that is, without prior motor experience) or overt response mode. The unexpected finding of equally large cardiac deceleration in the slow (versus fast) conditions may possibly reflect the high degree of attention (to the details of responding) required by the multiresponse nature of the task.
  6. Analyses of variance were performed on an IBM 360 computer with the use of the Biomed 08V program.
  7. R. W. Sperry, *Psychol. Rev.* 76, 532 (1969).
  8. J. R. Cautela, *Behav. Ther.* 1, 33 (1970).
  9. This is not to say that covert activity (as in the experiment reported here) occurs in the total absence of somatic involvement; for example, it has long been known that imagined somatic activities (for example, lifting an arm) can be detected in the appropriate musculature by means of sensitive electromyographic techniques [see E. Jacobson, *Amer. J. Physiol.* 91, 567 (1930)].

10. Some examples are as follows: J. Germana, *Psychophysiology* 6, 78 (1969); D. G. Kvasov and M. V. Korovina, in *Orienting Reflex and Exploratory Behavior*, L. G. Voronin, A. N. Leontiev, A. R. Luria, E. N. Sokolov, O. S. Vinogradova, Eds. (American Institute of Biological Sciences, Washington, D.C., 1965), p. 178; J. I. Lacey, J. Kagan, B. Lacey, H. A. Moss, in *Expressions of the Emotions in Man*, P. H. Knapp, Ed. (International Universities Press, New York, 1963), p. 161; K. H. Pribram and F. T. Melges, in *Handbook of Clinical Neurology*, P. J. Vinken and G. W. Bruyn, Eds. (North-Holland, Amsterdam, 1969), vol. 3, p. 316; F. K. Graham and R. K. Clifton, *Psychol. Bull.* 65, 305 (1966).
11. We thank S. Silverman for his help in collecting the data, and D. Shapiro and B. Tursky for their valuable comments. Research supported by the following National Institute of Mental Health grants: research scientist award K5-MH-20,476, research grant MH-08853, and postdoctoral fellowship MH-07084; and by the Office of Naval Research contract N00014-67-A-0298-0024 (Physiological Psychology Branch).

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## DDT: Disrupted Osmoregulatory Events in the Intestine of the Eel *Anguilla rostrata* Adapted to Seawater

**Abstract.** The drinking of seawater and absorption of water along with sodium across the intestinal epithelium are well-known osmoregulatory events in marine teleosts. The insecticide DDT impairs fluid absorption in intestinal sacs from eels adapted to seawater. Furthermore, this functional impairment has an enzymatic basis; DDT also inhibits the ( $\text{Na}^+$  and  $\text{K}^+$ ) activated,  $\text{Mg}^{2+}$ -dependent adenosine triphosphatase in homogenates of the intestinal mucosa. Thus, the extreme sensitivity of teleosts to organochlorine pollutants may involve the disruption of osmoregulatory transport mechanisms.

In view of the importance of marine fisheries to human nutrition (1), it is particularly alarming that fish are the most sensitive of all vertebrates to widespread organochlorine pollutants such as DDT (2). Although it is generally accepted that in both vertebrates and invertebrates DDT exerts a direct toxic effect on the nervous system, the biochemical basis is still uncertain (3). Because some evidence exists for inhibition of ( $\text{Na}^+$  and  $\text{K}^+$ ) activated transport adenosine triphosphatase in several organs including brain (4), we wondered if the extreme sensitivity of fish to DDT might not reflect parallel disruptions of osmoregulation and nerve function.

Marine teleosts face desiccation in their hypertonic environment. In part, they preserve tissue hypotonicity by drinking seawater and absorbing sodium and chloride across the intestinal epithelium. Water follows the absorption of these ions and is retained in the body while the ions are secreted by the gill epithelium (5). The adenosine triphosphatases appear to function in these osmoregulatory processes. The ( $\text{Na}^+$  and  $\text{K}^+$ ) activated,  $\text{Mg}^{2+}$ -de-

pendent adenosine triphosphatase [ $(\text{Na}^+, \text{K}^+, \text{Mg}^{2+})$  adenosine triphosphatase] which is sensitive to ouabain is believed to be involved in the transport of sodium across cell membranes (6). Supporting this hypothesis is the

fact that the activity of this enzyme in the intestinal mucosa of eels adapted to seawater is twice that seen in eels adapted to freshwater (7). Furthermore, there is evidence that the mitochondrial portion of the ( $\text{Mg}^{2+}$ ) adenosine triphosphatase which is the portion stimulated by 2,4-dinitrophenol is involved in oxidative phosphorylation (8). Thus by supplying ATP, this enzyme may be at least indirectly involved in active transport.

Eels (*Anguilla rostrata*) between 30 and 38 cm long were captured in estuaries along the Maine coast. They were adapted to and maintained in seawater ( $13^\circ$  to  $16^\circ\text{C}$ ) for 3 weeks before use. After decapitation, the intestines from the pyloric sphincter to the anus were excised. Intestines were cannulated and prepared for measurement of water absorption by means of a procedure in which noneverted sacs are used (9). Analytical grade *p,p'*-DDT (10) was dissolved in *N,N*-dimethylformamide (DMF) at a concentration of 10 mg/ml. Three media were used: Ringer, Ringer containing 0.5 percent DMF, and Ringer containing 0.5 percent DMF and a suspension of 50 parts of DDT per million (ppm). Each cannulated intestine was first incubated in its respective medium for 60 minutes at  $2^\circ$  to  $5^\circ\text{C}$ ; the medium was repeatedly rinsed through the lumen to allow DDT to enter the tissue. Then, each intestine was filled with its respective medium under slight hydrostatic pressure and sealed. The sacs were then incubated at  $15^\circ\text{C}$  in erlenmeyer flasks gassed with oxygen and containing additional medium. Thus, when present, DDT was on both the serosal and mucosal sides. Water absorption was calculated as sac weight at time 0 minus weight at 60 minutes and presented as microliters of  $\text{H}_2\text{O}$  per gram of intestine per hour.

When isolated sacs of eel intestine were incubated in  $1.4 \times 10^{-4}M$  DDT (50 ppm), there was a 47 percent

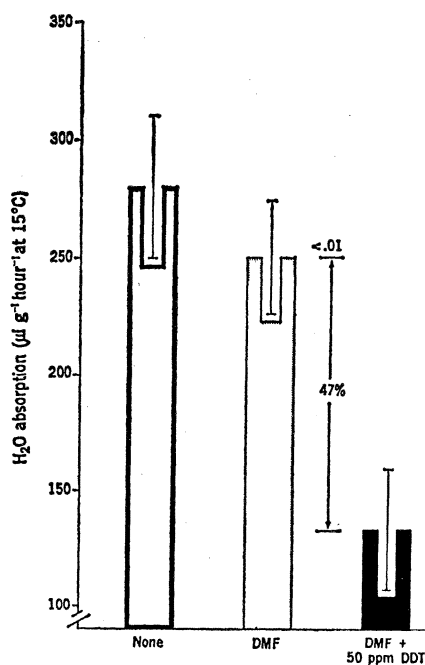


Fig. 1. The effect of DDT (final concentration 50 ppm, or  $1.4 \times 10^{-4}$  mole/liter) on water absorption in the intestine of the eel. The addition of 0.5 percent *N,N*-dimethylformamide (DMF) to the Ringer solution has no significant effect on intestinal water absorption ( $P > .3$ ). The addition of 50 ppm of DDT in DMF decreases water absorption 47 percent ( $P < .01$ ). The tops of the bars represent means; the vertical lines represent standard errors. Seven intestinal sacs were assayed in each medium.