
Orienting and Defense Reflexes: Vector Coding the Cardiac Response

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The notion of an orienting or "what-is-it" response (OR) emerged from Pavlov's (1927) studies of classical conditioning in dogs. Pavlov observed that a dog's conditioned response to a stimulus would fail to appear if some unexpected event occurred:

It is the reflex [OR] which brings about the immediate response in men and animals to the slightest changes in the world around them, so that they immediately orientate their appropriate receptor organ in accordance with the perceptible quality in the agent bringing about the change, making a full investigation of it. The biological significance of this reflex is obvious.
(p. 12)

Pavlov contrasted the OR with the defense response (DR), which he characterized as a "reflex of self-defense" with postural shifts and orientation of receptor organs away from rather than toward the stimulus.

The conceptions of the OR and DR, and methods for studying the OR and DR, have changed dramatically since Pavlov's seminal observations. We begin with a brief history of theory and research on the OR and DR, including the role psychophysiological measures generally, and phasic cardiac responses in particular, have played in studies of the OR and DR. We then survey recent theory and research on the autonomic substrates of autonomic (e.g., cardiac) responses and the utility of focusing on autonomic substrates rather than manifest visceral responses for advancing our understanding of the biological substrates and behavioral significance

cance of OR and DR. In view of theoretical developments, specific indices of sympathetic and parasympathetic control may provide a more detailed probing of the autonomic components of the OR and DR. Therefore, we conclude with representative research from eastern and western laboratories on noninvasive methods for estimating the autonomic origins of visceral responses.

CHANGING CONCEPTIONS OF THE ORIENTING AND DEFENSE RESPONSE

The OR and DR were initially conceptualized as having common and context-specific adjustments and were often treated as artifacts to be avoided in studies of classical conditioning. In *Perception and the Conditioned Reflex* (Sokolov, 1963), both conceptions were changed. The OR and DR were reformulated as biobehavioral phenomena that subserved perception and learning (e.g., by amplifying or reducing the effects of stimulation), evidenced many common features across evocative contexts, and could be quantified by psychophysiological measures. For instance, a distinction was made between the physiological adjustments that generalized across evocative stimuli and more stimulus-specific associated adaptational reflexes. In contrast to the adaptational responses, the autonomic components or signatures of both the OR and DR were posited to (a) be independent of stimulus quality, and (b) act directly on sense receptors and indirectly by feedback to central mechanisms to control receptor sensitivity. The OR and DR were further differentiated as follows: (a) an OR is elicited by stimuli of low or moderate intensity, whereas the DR is elicited by stimuli of high intensity; (b) an OR is marked by reciprocal peripheral vasoconstriction and cephalic vasodilatation, whereas the DR is associated with peripheral and cephalic vasoconstriction; (c) an OR has the same autonomic signature to the onset and offset of a stimulus because both represent changes in stimulation, whereas the autonomic response to stimulus onset is larger than to stimulus offset in the DR; and (d) the OR habituates rapidly to stimulus repetition, whereas the DR is either intensified or diminished much more slowly by stimulus repetition.

The intention was to provide a coherent and testable theory of the OR as an information regulator or filter. Thus, when an organism is exposed to a stimulus, this stimulus is represented in the central nervous system as a neuronal model. Subsequent stimuli are compared to this neuronal model. Discrepancies between these stimuli and the neuronal model result in physiological and behavioral changes that amplify perception of the stimulus (as well as updating the neuronal model), whereas matches

between a stimulus and the neuronal model diminish the perception of the stimulus. In this way, attention to changes or novelty is fostered and an organism's limited attentional resources are freed through habituation from the demands of constants in the continually unfolding transaction between the organism and the environment. The DR, in contrast, denotes threatening, noxious, or intense stimulation and is characterized as a biobehavioral response that served a protective function. Thus, the DR served a complementary role, fostering retreat from the provocative stimulus and a blunting of sensation to further reduce stimulation of the senses.

ORIENTING AND CARDIAC RESPONSES

Paralleling these developments, John and Beatrice Lacey (Lacey, 1959; Lacey, Kagan, Lacey, & Moss, 1963) also proposed that autonomic feedback to central neural structures amplifies or reduces the effects of environmental inputs. Specifically, the Laceys proposed that cardiac deceleration during psychological tasks was not only associated with attentional processes but could foster sensory intake, whereas cardiac acceleration was associated with and fostered sensory rejection. Among the evidence reviewed in support of this hypothesis were neurophysiological studies demonstrating that heart rate (HR) and blood pressure increases could decrease cortical excitation and increase sensory thresholds via baroreceptors in the carotid sinus and aortic arch. As Graham and Clifton (1966) noted, the notion that heart rate deceleration might mark increased sensory intake appeared to conflict with the suggestion (Sokolov, 1963) that increased sympathetic activity has a facilitating effect on sensory input through its excitatory effects on cortical activation. Graham and Clifton further noted, however, that the conflict was likely more apparent than real, as Sokolov had not dealt in depth with heart rate differences, and the Laceys had not examined tasks that were really comparable to those used to study the OR or DR.

In what has proven to be one of the most influential deductions in psychophysiology, Graham and Clifton (1966) reasoned that if the Laceys were correct in their inferences from neurophysiological evidence, heart rate deceleration should be able to predict changes in the kind of simple situations usually used to study the OR. More specifically, they wrote:

In inferring that similar cardiac responses should occur with the OR and during relatively prolonged attention to complex stimuli, it is not assumed that attention and orienting are identical processes. However, HR changes are presumed from Lacey's hypothesis to be especially relevant to the fea-

THE AUTONOMIC ORIGINS OF THE CARDIAC RESPONSES PROMOTED BY OR AND DR

Traditionally, the cardiac responses to environmental stimuli and challenges were thought to be determined by reciprocal central control of the sympathetic and parasympathetic nervous system, with increasing activity of one branch associated with decreasing activity of the other. It is now clear, however, that the cardiac responses to stimuli can be controlled centrally by reciprocal, uncoupled, or nonreciprocal (e.g., coactivational) changes in sympathetic and parasympathetic activation (see reviews by Bertinsson, Cacioppo, & Quigley, 1991, 1994; Bertinsson, Boysen, & Cacioppo, 1991). Recent evidence further suggests that cardiac responses to stimuli that appear at a nometabolic level to reflect the reciprocal actions of the sympathetic and parasympathetic branches of the autonomic nervous system mask consistent and profound individual differences in the mode of autonomic control (Bertinsson, Cacioppo, Binkley, et al., 1994; Cacioppo, Uchino, & Bertinsson, 1994; see review by Cacioppo, 1994). Given the antagonistic effects of the sympathetic and parasympathetic branches on, for instance, the chronotropic response of the heart, a tachycardic response to a stimulus may reflect uncoupled sympathetic activation, reciprocal sympathetic activation and vagal withdrawal, uncoupled vagal withdrawal, or even coactivation of the sympathetic and parasympathetic branches in which the effects of increases in the former exceed those of changes in the latter. Measures of heart rate responses *per se*, therefore, may not provide an accurate reflection of the underlying autonomic response.

Vector Coding

The study of perception (color vision), targeting responses (eye and head movements), and instrumental conditioning (in fish, rabbits, and monkeys) has suggested vector code in neuronal networks as a basic principle of information processing (Sokolov, 1994, 1995; Sokolov & Vaitkyavicus, 1989). The mapping of behavioral-physiological relationships (e.g., autonomic components of the OR and DR) and our understanding of the adaptive significance and mechanism underlying these relationships, may also be advanced by using vector coding to distinguish among similarly manifesting cardiac responses that differ in their autonomic determinants. In the case of the heart, this can be done by replacing the conceptualization of heart rate responses as a unidimensional (e.g., sympathetic activation) vector with a bivariate autonomic plane. Bertinsson, Cacioppo, and Quigley (1991, 1993a) recently outlined such a bivariate autonomic space and reviewed the evidence consistent with the notion that HR reactivity can derive from multiple modes of autonomic control including but not limited to the reciprocal mode of cardiac control. The model entails a bivariate

ture that both processes have in common and that both Sokolov and the Lacey's have emphasized—the feature of enhancing sensitivity to environmental inputs. (p. 306)

As predicted by Graham and Clifton (1966), the phasic HIR response to stimuli has proven to be a more reliable and discriminating index of ORs and DRs in the Western literature than cephalic or peripheral vaso-motor changes, with the OR associated with phasic bradycardic responses and the DR associated with tachycardia (Graham, 1979, 1984; Turpin, 1986). Graham (1979, 1984) also specified the physical parameters of the stimuli that elicit the OR and DR: the OR was characterized as more likely to be elicited by novel stimuli of low to moderate intensity with slow rise-times, and the DR was characterized as preferentially elicited by intense or aversive stimuli. Graham (1979, 1984) also noted that both DRs and startle responses are associated with cardiac acceleration but proposed that startle responses are preferentially elicited by stimuli with fast rise-times, are associated with shorter latency tachycardic responses, and habituate more quickly than DRs.

The concepts of OR and DR, and their autonomic signatures, are among the most heavily investigated topics in psychophysiology. Cardiac responses are complexly determined autonomic responses that can be influenced by basal conditions and various "adaptational reflexes" (e.g., stimulus significance, motivational and somatic factors), however. Although the OR may promote bradycardia, skin conductance responding, peripheral vasoconstriction, and cephalic vasodilation and the DR may promote slow habituating tachycardia, skin conductance activity, and both peripheral and cephalic vasoconstriction (Sokolov, 1963), other influences may obfuscate these autonomic outcomes. For instance, cephalic vasomotor responses to orienting stimuli have not been particularly replicable across eastern and western laboratories. It is conceivable, however, that methodological differences in eastern and western laboratories, through their effects on basal conditions or adaptational reflexes, altered the form of the cephalic vasomotor response that was observed to orienting stimuli. For instance, recent studies using PET and MRI have shown a novelty-dependent increase in rCBF in humans (Tulving, Markowitsch, Kapur, Habib, & Houle, 1994), whereas pain stimulation was associated with a partial reduction in rCBF (Coghill et al., 1994; Gulyas, Roland, Heywood, Popplewell, & Cowey, 1994). Alternatively, questions could be raised about the generality of the autonomic markers of the OR and DR and the utility of the concepts of OR and DR (e.g., see Saiers, Richardson, & Campbell, 1990; Turpin, 1986). Such questions have helped stimulate new theoretical analyses of the OR and DR, a topic to which we turn next.

vector space bounded by sympathetic and parasympathetic axes and reflecting all possible combinations of activities of the two autonomic divisions (see Fig. 1.1). Any baseline HR in this autonomic plane is specified by its cartesian coordinates along the autonomic axes, and phasic autonomic responses are characterized by movements within this autonomic plane.

The functional state of a visceral organ (e.g., the heart) for any location in autonomic space is represented along a third axis as specified by the following general equation (Berntson, Cacioppo, & Quigley, 1991):

$$f_{ij} = b + cs*si + cp*pj + l_{ij} + e \quad (1)$$

where f_{ij} is the functional state of the target organ for any i (sympathetic) and j (parasympathetic) input or locus in autonomic space, b is the intrinsic heart period in the absence of autonomic inputs, si and pj are the independent activities of the sympathetic (i) and parasympathetic (j) innervations at point ij , and cs and cp are coupling coefficients that reflect the relative impact of sympathetic and parasympathetic activities on the visceral organ (e.g., heart period).¹ l_{ij} reflects potential interactions among the ANS divisions, and e is the error term.²

Equation 1 makes it possible to characterize the functional state of the heart for any locus on the bivariate autonomic plane by describing an overlying effector (i.e., cardiac response) surface, yielding a three-dimensional depiction of autonomic space. The mean values for each of the

¹ c_s and c_p can be conceptualized as the dynamic ranges of the sympathetic and parasympathetic autonomic branches, respectively. In the case of the heart, for instance, $c_s = HP_s(\max) - \beta$ and $c_p = HP_p(\max) - \beta$, where $HP_s(\max)$ is the heart period at isolated maximal sympathetic activation and $HP_p(\max)$ is the heart period at isolated maximal parasympathetic activation.

²Equation 1 can be conceptualized in various ways. For instance, assuming $l_{ij} = 0$ and $e = 0$, factoring out the intrinsic heart period (i.e., the background period of the pacemaker of the sinus node) in Equation 1 results in:

$$f_{ij} = \beta(1 + c_s/\beta*s_i + c_p/\beta*p_j) \quad (2)$$

where f_{ij} = heart period under stimulation ij , c_s/β = sympathetic synaptic weight on the pacemaker cells, and c_p/β = parasympathetic synaptic weight on the pacemaker cells. c_s/β and c_p/β can be conceptualized as the components of synaptic weights of a weight vector C . Similarly, S_i and P_j can be conceptualized as components of an excitation vector, E . $c_s/\beta*s_i + c_p/\beta*p_j$ = inner product of the weight vector C and the excitation vector E , that is, (E, C) . Thus, Equation 2 can be rewritten as follows:

$$f_{ij} = \beta(1 + (E, C)) \quad (3)$$

The heart period is equal to the background pacemaker period β multiplied by background activation of the pacemaker plus the inner product of the excitation vector E and weight vector C .

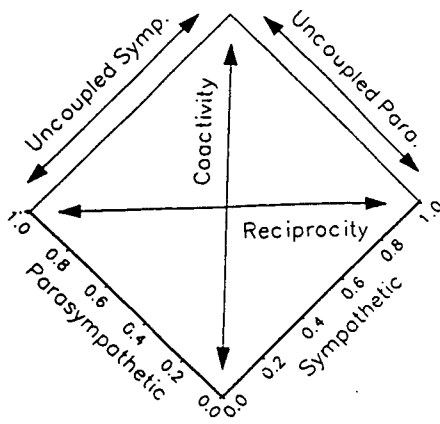


FIG. 1.1. Two-dimensional representation of autonomic space. Axes are expressed in proportional units of activation of the sympathetic and parasympathetic branches. The arrow extending from the left to the right axes intersections depicts the diagonal of reciprocity. The arrow extending from the back to the front axes intersections represents the diagonal of coactivity. The arrows along the axes depict uncoupled changes in the single autonomic nervous system divisions. These arrows, and vectors parallel to them, illustrate the major modes of autonomic control. From Berntson, Cacioppo, and Quigley (1993a). Reprinted with permission.

parameters in Equation 1 have been determined for humans (Berntson et al., 1993a) and for rats (Berntson, Cacioppo, Quigley, & Fabro, 1994). Berntson et al. (1993a) found considerable individual differences in the intrinsic heart period in humans, as well as phasic nonautonomic contributions to heart period (e.g., temperature, exercise). However, the cardiac effector surface reflecting neurally determined changes in heart period in humans is depicted in Fig. 1.2 where, on average, $cs = -230$ ms and $cp = 1,713$ ms (Berntson et al., 1993a).

An important feature of the effector surface depicted in Fig. 1.2 is that the same heart rate response can occur for very different reasons. A deceleratory heart rate response may occur due to vagal activation, sympathetic withdrawal, or various combinations of the two. Thus, a given heart period may be ambiguous with regard to its autonomic origins. This is depicted as isoeffector contour (dotted) lines in Fig. 1.2. These contours illustrate the multiple loci on the bivariate vector plane that yield equivalent cardiac responses. The many-to-one mapping from the autonomic plane to the effector surface underscores the indeterminism when inferring changes in autonomic activities or behavioral processes based solely on changes in cardiac response (Cacioppo & Tassinari, 1990).

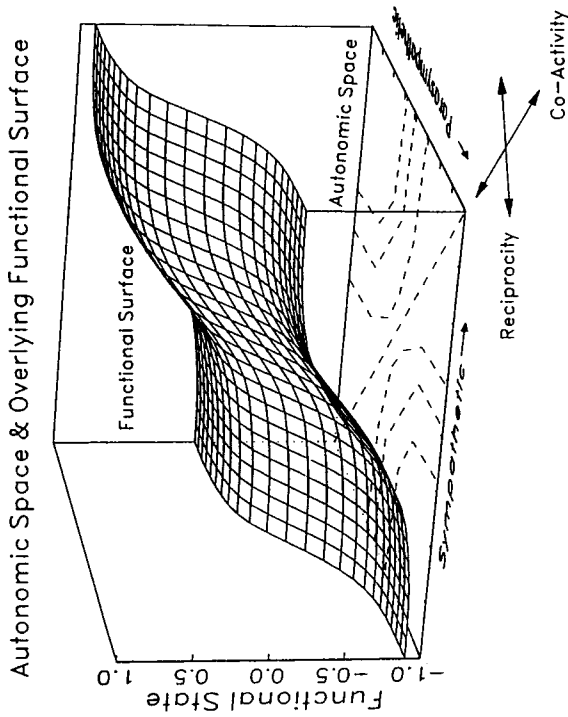


FIG. 1.2. Two-dimensional autonomic plane and its associated functional surface. The functional surface represents the operational state of the target organ, expressed in relative units, as derived from Equation 1 with weighting coefficients = +1.0. The axes dimensions are in decile units of functional activation. Dotted lines represent isofunctional contour lines projected on the autonomic plane, illustrating loci within the autonomic plane that have equivalent functional outputs. The arrows indicate the directional vectors associated with the modes of autonomic control. From Bertson, Cacioppo, and Quigley (1991). Reprinted with permission.

Autonomic Origins of the OR and DR as Revealed by Autonomic Blockade

Because identical cardiac responses may arise from different autonomic loci, Bertson et al. (1993a; Bertson, Boysen, & Cacioppo, 1991) suggested that information beyond the description of the cardiac response may contribute to the differentiation of the OR and DR. Quigley and Bertson (1990), for instance, presented brief nonsignal acoustic tones of two intensities (60 vs. 80 dB, SPL) to evoke bradycardia and tachycardia, respectively, in rats (see Fig. 1.3). The administration of the postganglionic parasympathetic antagonist, scopolamine methyl nitrate, and the sympathetic β_1 antagonist, atenolol, further revealed the autonomic origins of these cardiac responses. The tachycardic response to the high-intensity stimulus, which would appear to reflect a DR, was attributable primarily to sympathetic

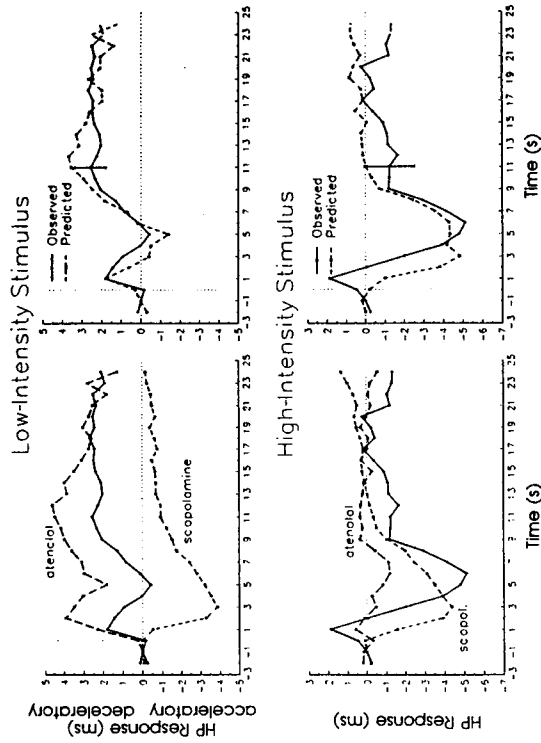


FIG. 1.3. Autonomic cardiac control during postinfusion baseline period as revealed by autonomic blockades. Left panel: Mean heart rate under saline, atropine sulfate, metoprolol, and double blockade. Middle panel: Mean respiratory sinus arrhythmia under saline, atropine sulfate, metoprolol, and double blockade. Right panel: Mean pre-ejection period under saline, atropine sulfate, metoprolol, and double blockade. The terms, *s* and *p* at the top of each panel represent quantitative estimates of the sympathetic and parasympathetic contributions, respectively, to the corresponding error in the quantitative estimates based on autonomic blockades. Quantitative estimates with dissimilar superscripts differ at $p < .05$. From Cacioppo (1994). Reprinted with the permission of Cambridge University Press.

activation, as it was diminished dramatically by atenolol and affected only minimally by scopolamine. Conversely, the bradycardic response to the low-intensity stimulus, which would appear to reflect an OR, reflected both strong vagal activation and a less potent sympathetic activation to the stimulus. That is, vagal blockade by scopolamine not only eliminated the deceleratory cardiac response to the stimulus but unmasked a significant acceleratory response to the stimulus, and sympathetic blockade enhanced substantially the bradycardic response to the low-intensity stimulus (see Fig. 1.3). These observations are consistent with the coactivation of the parasympathetic and sympathetic branches controlling the heart in the OR. The vector approach in the autonomic space model differentiates the OR and DR by their specific trajectories on the functional surface overlying the autonomic plane.

Although the manifest cardiac responses in Quigley and Bertnson (1990) may have been sufficient to differentiate the OR and DR to low- and high-intensity tones, respectively, a recognition of the multiple determinants of autonomic responses and the multiple modes of autonomic control underlying these responses may increase the power and specificity of cardiac measures of OR and DR (Bertnson et al., 1993a). For instance, Richardson, Siegel, and Campbell (1988) found that the transfer of rats to an unfamiliar testing environment inhibited the cardiac component of the OR to a pulsating tone. Sainers et al. (1990) replicated these findings in preweaning rats and observed similar results following electric shock. Because the stimulus change (pulsating tone) was the same across contexts, the authors interpreted their results as inconsistent with contemporary conceptualizations of the OR. As Quigley and Bertnson (1990) suggested, however, the cardiac component of the OR appears to be characterized by coactivation of the vagal and sympathetic branches—a neural substrate that, with small changes in activation of either branch, can mask consistent effector responses (Bertnson, Boysen, & Cacioppo, 1991). Moreover, novel or challenging environments may be especially likely to promote coactivation of the sympathetic and parasympathetic divisions to foster directional flexibility in effector outcomes. As Bertnson et al. (1993a) noted:

The attenuated cardiac orienting responses reported by Richardson et al. (1988) and Sainers et al. (1990) could reflect greater conjoint parasympathetic and sympathetic activation (i.e., coactivation), rather than an attenuation of the vagal response associated with the OR (Quigley & Bertnson, 1990). Examination of the second x second HR changes in the Sainers et al. study (their Fig. 6) supports this interpretation. The sympathetic system is known to have a longer latency than vagal influences on the heart. . . . In the Sainers et al. study, the experimental manipulations (shock or context change) did not alter the heart rate response during the first second after the stimulus, rather experimental curves progressively diverged from the control condition over the subsequent 2 to 3 sec. This is consistent with a concurrent (longer latency) sympathetic activation, which would obscure the vagal response. Autonomic co-activation is also consistent with the absence of baseline increases in heart rate in the Sainers et al. study, even after repeated shocks. (p. 195)

The vector representation of the OR and DR in terms of sympathetic and parasympathetic components may also elucidate the vascular differences in cephalic and peripheral response, with the DR associated with general sympathetic vasoconstriction and the coactivation of sympathetic and parasympathetic influences elicited by OR producing peripheral vasoconstriction but more variable cephalic vasomotor manifestations across eastern and western laboratories.

NONINVASIVE INDICES OF AUTONOMIC SUBSTRATES

In view of these considerations, specific indices of sympathetic and parasympathetic control may provide a more detailed probing of the autonomic components of OR and DR. For instance, the cardiac OR to a novel stimulus and to an adaptively meaningful stimulus may share common features but the attentional, cognitive, and behavioral dispositions toward these classes of stimuli may differ. Independent measures of the relative activities of the sympathetic and parasympathetic divisions may improve the resolution of the autonomic measures and help illuminate the common and context-specific autonomic components of the OR and DR. Research on these issues from western and Moscow laboratories is described in this section.

One approach that sometimes serves as a standard against which other approaches are measured involves the use of pharmacological blockades. Although not without problems, autonomic blockades provide information about the contributions of each of the autonomic divisions to responses from specific effector organs (for a detailed discussion of the underlying logic, see Bertnson, Cacioppo, & Quigley, 1994). Autonomic blockades may be especially appropriate when the autonomic components of punctate responses are of interest because they allow moment-by-moment estimation of the neural determinants of visceral responses.

Noninvasive indices of sympathetic and parasympathetic contributions to effector responses may also be helpful, particularly when the autonomic components of the OR or DR are extended in time (e.g., Sainers et al., 1990). For instance, two of the more promising noninvasive measures of the autonomic control of the heart currently available are the cardiac pre-ejection period and respiratory sinus arrhythmia. The pre-ejection period is a systolic time interval representing the period of time commencing with the onset of ventricular depolarization (ECG Q-wave) and ending with the opening of the semilunar valves. The greater the sympathetic activation of the myocardium and the greater the myocardial contractility, the shorter the pre-ejection period as long as the effects of preload and afterload are controlled or are held constant (Binkley & Boudoulas, 1986). A shortening of the pre-ejection period accompanies increases in HR that derive from adrenergic cardio stimulation but not from vagal blockade or atrial pacing (e.g., Harris, Schoenfeld, & Weissler, 1967). Studies further suggest that HR per se does not influence the pre-ejection period unless changes in HR are associated with inotropic changes, or are accompanied by changes in preload or afterload (Lewis, Leighton, Forester, & Weissler, 1974).

Respiratory sinus arrhythmia refers to the high-frequency (e.g., 0.12–0.40 Hz in adults) component of the oscillations of heart period produced

by respiratory processes. For instance, the inspiratory and expiratory phases of the respiratory cycle are associated with HR acceleration and HR deceleration, respectively. The magnitude and changes in respiratory sinus arrhythmia appear to vary as a function of vagal control of the heart as long as significant variations in respiratory activity are controlled or accounted for (Berntson, Cacioppo, & Quigley, 1993a; Grossman, Karemaker, & Wieling, 1991).

Accurate measurement of the pre-ejection period and respiratory sinus arrhythmia requires analyses of a series (e.g., 60 secs) of heartbeats. This requirement has limited the usefulness of these noninvasive measures in most studies of OR and DR in humans. However, orienting and defense reflexes have been studied in animals using, for instance, pulsating tones over sufficiently long periods (e.g., see Saiters et al., 1990) that noninvasive indices become feasible.

In a study of the psychometric properties of pre-ejection period and respiratory sinus arrhythmia, cardiovascular and respiratory measures were made during a 2-min standing baseline and a 2-min sitting baseline (Cacioppo, Berntson, et al., 1994). After baseline testing, subjects were given 4 min to prepare and 4 to 5 min to present a public speech. Approximately half (2 min) of the speech was delivered while seated, and approximately half (2 min) of the speech was delivered while standing. (The postural manipulation allowed examination of the reliabilities of respiratory sinus arrhythmia and pre-ejection period reactivity at two different levels of the autonomic activation of the heart.) After speaking for 2 min, the recordings were paused surreptitiously, and subjects were instructed to change posture and to continue their speech. Subjects assumed the alternate posture (standing or sitting) and continued speaking. The recordings were surreptitiously initiated 30 sec later and continued for another 2 min, at which point recordings were stopped and subjects were instructed that they had done well and could stop.

Nomethetic analyses indicated that the HR responses to the speech task were the result of the reciprocal activation of the sympathetic and parasympathetic branches: The speech stressor led to an elevation in HR, a reduction in respiratory sinus arrhythmia (depicting vagal cardiac withdrawal), and a shortening of pre-ejection period (indicating sympathetic cardiac activation). Idiographic analyses of these data, however, revealed considerable individual differences, with an exaggerated HR response to the stressor arising from various modes of control, ranging from strong parasympathetic withdrawal to reciprocal increases in sympathetic, and decreases in parasympathetic, activation to large increases in sympathetic activation. Among the high HR reactors, for instance, were three subgroups: individuals who showed primarily vagal cardiac withdrawal, individuals who showed primarily sympathetic cardiac activation, and individuals who showed both vagal cardiac withdrawal and sympathetic cardiac activation.

Psychometric Properties

Analyses of the measurement properties of the baseline, task, and reactivity (simple and residualized change) measures of HR, pre-ejection period, and respiratory sinus arrhythmia were also conducted. The internal consistency of each of these indices was examined by calculating Cronbach alphas across baseline and task periods within each posture, and again after aggregating across postures. The Cronbach alphas for the entire sample of 67 projects ranged from .79 to .91, with aggregation modestly improving the Cronbach alpha for each index ($ps < .001$).

If individuals are to be classified not only in terms of their HR reactivity but also in terms of vagal and sympathetic cardiac reactivity, then ideally HR reactivity, respiratory sinus arrhythmia reactivity, and pre-ejection period reactivity should yield consistent classifications of individuals in terms of their level of reactivity. To examine this question, rank orderings of subjects were constructed in terms of their HR, respiratory sinus arrhythmia, and pre-ejection period reactivity in the sitting posture, and corresponding rank orderings were constructed in terms of their reactivity on each measure in the standing posture. The Spearman correlation for each measure was then computed to determine the stability of the rank orderings across posture—that is, at two different levels of tonic autonomic control of the heart. These analyses were then repeated using residualized change scores. In every instance, the Spearman coefficient was statistically significant at the $p < .01$ level despite differences in basal autonomic tone across posture. Furthermore, the reliability statistics for classifying individuals in terms of stress-induced respiratory sinus arrhythmia reactivity and in terms of pre-ejection period reactivity were comparable to those for HR reactivity ($ps < .01$).

Next, basal HR, task HR, and HR reactivity (calculated as a simple change score and as a residualized change score) during sitting were correlated with the corresponding index during standing to determine test-retest reliabilities, and comparable analyses were performed for the indices based on respiratory sinus arrhythmia and on pre-ejection period. Results revealed that these test-retest correlations ranged from .53 to .82 ($ps < .01$). The finding that HR, respiratory sinus arrhythmia, and pre-ejection period reactivity indices during sitting were highly predictive of the corresponding reactivity measures during standing, although limited to the present paradigm (cf. Sloan et al.), is encouraging from the viewpoint of measuring the autonomic substrates of cardiac response.

The interrelationships among the reactivity measures were also consistent with the use of respiratory sinus arrhythmia and pre-ejection period reactivity as noninvasive indices of the vagal and sympathetic determinants, respectively, of cardiac responses. First, the correlations between stress-induced changes in respiratory sinus arrhythmia and in

HR were all negative, reflecting the negative chronotropic effects of vagal input to the heart. That is, individuals who displayed stress-induced increases in respiratory sinus arrhythmia also were likely to show small increases in HR, whereas individuals who showed stress-induced decreases in respiratory sinus arrhythmia (reflecting vagal withdrawal) also displayed large increases in HR. Furthermore, the median correlation among these measures was statistically significant (median $r = -.53, p < .01$). Second, the correlations among stress-induced changes in pre-ejection period and in HR were uniformly large and negative, consistent with the notion that stress-induced sympathetic cardiac activation shortens pre-ejection period and elevates HR. The median correlation among these measures was also statistically significant (median $r = -.54, p < .01$). Finally, the correlations between the respiratory sinus arrhythmia and pre-ejection period reactivity measures revealed that these indices did not consistently covary across individuals, and the median correlation among these measures was not significant (median $r = .29, ns$). The results of this study, therefore, were consistent with the notion that stress-induced changes in respiratory sinus arrhythmia and in pre-ejection period can vary independently, and that each may predict unique autonomic determinants of cardiac response.

Autonomic Blockade Analyses of Respiratory Sinus Arrhythmia and Pre-Ejection Period

The use of respiratory sinus arrhythmia and pre-ejection period to index stress-induced changes in the autonomic control of the heart is not without problems or controversy, and alternative indices (e.g., rate-corrected pre-ejection period, low-frequency heart period variability) have been proposed in the psychophysiological and cardiologic literatures. The cardiac rhythm spectrum, for instance, typically contains three main peaks. The high-frequency peak (around 0.25 Hz) is related to respiratory sinus arrhythmia representing parasympathetic input to the heart. The low-frequency peak (around 0.10 Hz) is influenced primarily by vascular rhythmicity and, therefore, has been thought to reflect sympathetic input to the heart. Finally, metabolic (humoral) influences have a greater impact on the very low-frequency peak (around 0.01 Hz) than on the low- or high-frequency peaks. Spectral analysis provides one means of decomposing the heart period time series into frequency components, making it possible to quantify the high, low, and very low frequency amplitudes. However, whether these amplitudes reflect vagal, sympathetic, and humoral control of the heart, respectively, or whether statistical procedures can be developed to improve these indices remains an important area for future research. For instance, Cacioppo, Bertson, et al. (1994) reported a

a single and double autonomic blockade study to evaluate various putative measures of autonomic control of the heart, including pre-ejection period and low-frequency HR variability as indices of sympathetic control of the heart, and respiratory sinus arrhythmia as an index of parasympathetic control of the heart. Although autonomic blockades can help illuminate the underlying autonomic origins of cardiac indices, systematic biases in estimates of the contributions of the autonomic branches can arise from both methodological and physiological factors (e.g., due to interactions among the autonomic branches at the level of the organ; indirect or reflexive alterations in the unblocked branch; nonselective actions of the blocker agents). Consequently, autonomic estimates that were based on data from single and double blockade conditions were developed to quantify systematic biases as well as the neural contributions of each autonomic division (Bertson, Cacioppo, & Quigley, 1994).

Subjects were tested under three drug conditions (saline, atropine sulfate, metoprolol) on three consecutive days, with drug condition counterbalanced across subjects and days. Cardiovascular and respiratory measures were obtained prior to and following infusion of either saline (Saline Condition), atropine sulfate (Atropine Condition), or metoprolol (Metoprolol Condition). Subjects who qualified for participation in the study were tested under all three drug conditions, and the order of drug administration was counterbalanced across subjects. Following venipuncture at each session, subjects rested quietly for 30 min to allow adaptation to the laboratory, and initial baseline recordings were made during the final 3 min of this adaptation period. Intravenous infusion of saline, metoprolol (14 mg), or atropine sulfate (2 mg) followed (using a double-blind procedure), and subjects sat quietly for 15 min. Recordings were taken during the final 3 min of this postinfusion baseline and in response to an orthostatic stressor (3 min standing, 3 min sitting, order counterbalanced). Afterward, subjects were exposed to 3 min reaction time, mental arithmetic, and speech stressors, with a resting 3 min baseline preceding each stressor, and the order of stressors counterbalanced across days and subjects. At the end of the metoprolol session, atropine sulfate was infused and responses were monitored during the postinfusion (i.e., double blockade) baseline and during orthostatic stressor (Bertson, Cacioppo, Binkley, Uchino, Quigley, & Fieldstone, 1994; Cacioppo, Bertson, Binkley, et al., 1994).

Analyses revealed that drug condition was unrelated to the cardiovascular measures at preinfusion baseline, as would be expected given the counterbalancing and double-blind procedures that were used. As illustrated in the left panel of Fig. 1.4, HR during the postinfusion baseline varied significantly as a function of autonomic blockade, with mean HR under saline about 72 beats per minute (bpm), under atropine about 119

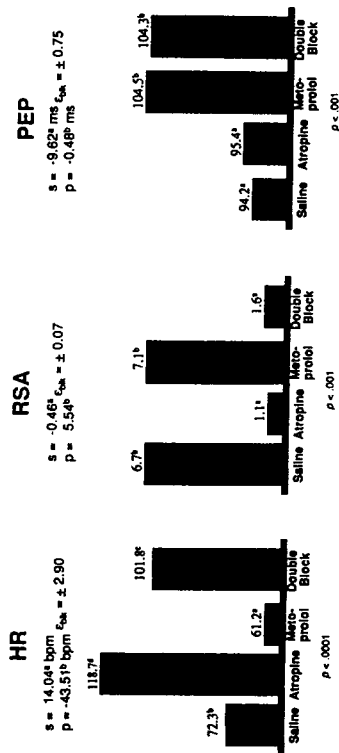


FIG. 1.4. Mean cardiac response of rats to a nonsignal acoustic stimulus of low intensity (60 dB) and high intensity (80 dB). Left panels illustrate the heart period responses in the unblocked condition (solid lines) and after sympathetic (atenolol, 5 mg/kg) or parasympathetic (scopolamine methyl nitrate, 0.1 mg/kg) blockade. Right panels illustrate the observed response in the unblocked condition and the predicted responses based on the independent responses of the autonomic branches under selective blockades. Error bars depict illustrative standard errors for the unblocked response. Data from Quigley and Bertson (1990). Figure from Bertson, Cacioppo, Quigley, and Fabro (1994). Reprinted with the permission of Cambridge University Press.

bpm, under metoprolol about 61 bpm, and under double blockade 101 bpm ($p < .01$). Quantitative analyses indicated that sympathetic contributions to basal HR averaged 14 bpm and parasympathetic contributions to basal HR averaged -43.5 bpm (Cacioppo, Bertson, Binkley, et al., 1994).

Analyses of the blockade data further revealed that pre-ejection period reflected sympathetic but not vagal influences on the heart, and respiratory sinus arrhythmia (high-frequency cardiac variability) reflected vagal and only nominal sympathetic influences on the heart. Quantitative analyses of the postinfusion baseline data, for instance, indicated that sympathetic contributions to respiratory sinus arrhythmia averaged less than 0.5 log units, whereas parasympathetic contributions averaged over 5.5 log units. The quantitative analyses revealed the opposite to hold for pre-ejection period: sympathetic contributions averaged -9.6 ms, whereas parasympathetic contributions averaged -0.5 ms and fell within the range of error bias (see Fig. 1.4, middle and right panels, respectively). Importantly, analyses of low-frequency cardiac variability revealed the measure to be affected by vagal as well as sympathetic contributions, with the magnitude of the former exceeding that of the latter under resting conditions. Analyses of the cardiac responses to the orthostatic stressor under

single and double autonomic blockade replicated these results. Although the blockade results for high- and low-frequency components of the cardiac rhythm spectrum are consistent with the frequency characteristics of the vagal and sympathetic cardiac synapses (Bertson, Cacioppo, & Quigley, 1993b), they point to the need for additional research and, possibly, the development of more complex analytical methods before the measure of low-frequency HR variability can serve satisfactorily as a specific marker of sympathetic control of the heart.

Heart Rate Variability Spectral Peaks as Measures of Underlying Mechanisms

Although analyses of both high- and low-frequency HR variability by Cacioppo, Bertson, Binkley, et al. (1994) suggested that there were parasympathetic contributions to both frequencies, these components of HR variability reflect different aspects of the vagal and sympathetic control of the heart. As noted, the very low-frequency peak reflects a combination of metabolic influences (e.g., humoral, temperature, baroreceptor); the low-frequency peak reflects vascular influences; and the high-frequency peak, respiratory influences. Analyses of the contributions by an autonomic branch (e.g., parasympathetic) to each of these peaks indicate that they may not be highly correlated and that the magnitude of the correlation may vary across conditions (e.g., baseline, stress). Thus, the "amount" of vagal control of the heart may vary depending on which spectral peak or bandwidth is quantified. This points to limitations in using noninvasive measures such as respiratory sinus arrhythmia to gauge the vagal control of the heart. More interestingly, it raises another potentially fruitful approach to investigating the neural mechanisms underlying the OR and DR: The amplitude of each of the three spectral peaks in heart rhythm variability, which conceivably reflect separable mechanistic influences, can be used to decompose and map the cardiac response in a three-dimensional space. The orthogonal axis representing high-, medium-, and low-frequency bands suggest an independence of three generators operating in parallel and constituting a three-dimensional vector in the frequency domain (Danilova, 1995; Sokolov, 1995).

To illustrate, HR variability was measured in the Moscow laboratory in 90 (45 low-anxious and 45 high-anxious) subjects under conditions of rest and mental arithmetic. Spectral analyses confirmed that high-, in contrast to low-, anxious subjects were characterized by depressed spectral components in HR variability (see Fig. 1.5). Next, a 10×10 correlation matrix of respective frequency bands was constructed for each condition (rest, mental arithmetic). Factor analyses revealed three orthogonal factors

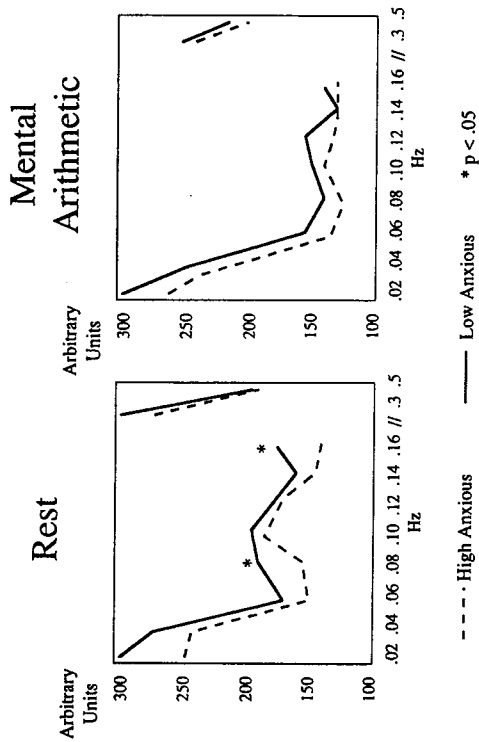


FIG. 1.5. The heart rhythm spectrum in high-anxious (HA) and low-anxious (LA) subjects during rest (top panel) and mental arithmetic (bottom panel). The high- and low-frequency heart rhythms were higher in low- than high-anxious subjects during rest, and were higher generally during rest than during the stressor. Adapted from Danilova (1995). Reprinted with permission.

corresponding to what might be labeled respiratory, vascular, and metabolic oscillators. The same three factors were found during rest as during mental arithmetic.

Using these three factors as a coordinate system, the cardiac responses of high-anxious and low-anxious subjects can be depicted in a three-dimensional space and projected on three planes for the resting condition. Analyses of the configuration of these peaks revealed that the high- and low-anxious groups differed dramatically in terms of the underlying organization of their baseline HR variability. The HR variability of low-anxious subjects was not only greater than that characterizing high-anxious subjects, but this difference appeared to derive from metabolic, vascular, and respiratory influences. Similar analyses were performed on HR variability during mental arithmetic, revealing substantial vagal withdrawal and depressed high-frequency variability (i.e., respiratory sinus arrhythmia) in both groups. Thus, differences between the low- and high-anxious subjects in the underlying organization of HR variability during mental arithmetic were evident primarily in the low (vascular) and very low (metabolic) frequency components. If one assumes that anxious subjects are characterized by a chronic defensive disposition, these data suggest that the highly (in contrast to mildly)

anxious subjects show depressed levels of heart period variability during baseline similar to those observed during a psychological stressor (mental arithmetic) in low- and high-anxious subjects.

The fact that both sympathetic and vagal activation can influence very low and low frequency components makes it difficult to use these components to separate the contributions of each autonomic branch to cardiac responses. Furthermore, the vagal contribution to cardiac control, as reflected in high-frequency heart rhythms in the study of high-anxious and low-anxious subjects, was not correlated with, or was inconsistently correlated with, the vagal contribution as indexed in low or very low frequency heart rhythms. This result casts doubt on the validity of estimates of sympathetic influences that "correct" for the vagal influences in the low-frequency HR variability using estimates of vagal activation from high-frequency heart rhythms. It may be possible and illuminating, however, to relate the frequency peaks in the heart rhythm spectra to metabolic, vascular, and respiratory mechanisms, and in so doing to examine the OR and DR in terms of the contributions of each of these mechanisms to cardiac responses. Given the particular tasks the low- and high-anxious subjects performed, extrapolation of these particular data to the OR and DR is tenuous. However, the approach illustrated in this study may shed new light on the biobehavioral significance of the OR and DR reflexes. Because these measures require a time series of heartbeats, these noninvasive measures may be especially suited to tasks designed to study attention such as those developed by Lacey et al. (1963) and to relatively long orienting or defense stimuli such as those developed by Campbell and colleagues (Richardson et al., 1988; Saiters et al., 1990).

SUMMARY

Perception and the Conditioned Reflex (Sokolov, 1963) opened a fertile area of psychophysiological theory and research on the OR and DR. Graham (1979, 1984; Graham & Clifton, 1966) expanded this area by focusing on the cardiac components of the OR and DR. In the 30 years since Graham first drew attention to the cardiac response as a tool for probing these reflexes, empirical anomalies have appeared that have led some to question the utility of the concepts of OR and DR. One possible resolution is to examine the autonomic origins of the cardiac components of the OR and DR rather than focusing exclusively on the cardiac response per se. At present, autonomic blockades provide the clearest means of determining these autonomic substrates, but specific and sensitive noninvasive indices of vagal and sympathetic influences on the cardiac components of the OR and DR would represent important advances. Such measures would allow an

unambiguous specification of autonomic response and would likely contribute to meaningful investigations of behavioral-psychophysiological relationships (Bertson et al., 1993a). Another possibility is to map cardiac components of the OR and DR in terms of their physiological (humoral, vascular, respiratory) determinants. Although representing quite different approaches, both are based on the notion that our understanding of biobehavioral organization and control, as represented in the OR and DR, may be advanced by quantifying the neurophysiological origins of these responses. Finally, the bivariate approach to the study of OR and DR is based on the principle of a vector code operating within sympathetic-parasympathetic inputs, a principle that can be extended to frequency-specific independent generators contributing to heart rate variability.

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REFERENCES

- Bertson, G. G., Boysen, S. T., & Cacioppo, J. T. (1991). Cardiac orienting and defensive responses: Potential origins in autonomic space. In B. A. Campbell (Ed.), *Attention and information processing in infants and adults* (pp. 163-200). Hillsdale, NJ: Lawrence Erlbaum Associates.
- Bertson, G. G., Cacioppo, J. T., Binkley, P. F., Uchino, B. N., Quigley, K. S., & Fieldstone, A. (1994). Autonomic cardiac control: III. Psychological stress and cardiac response in autonomic space as revealed by autonomic blockades. *Psychophysiology*, *31*, 599-608.
- Bertson, G. G., Cacioppo, J. T., & Quigley, K. S. (1991). Autonomic determinism: The modes of autonomic control, the doctrine of autonomic space, and the laws of autonomic constraint. *Psychological Review*, *98*, 459-487.
- Bertson, G. G., Cacioppo, J. T., & Quigley, K. S. (1993a). Cardiac psychophysiology and autonomic space in humans: Empirical perspectives and conceptual implications. *Psychological Bulletin*, *114*, 296-322.
- Bertson, G. G., Cacioppo, J. T., & Quigley, K. S. (1993b). Respiratory sinus arrhythmia: Autonomic origins, physiological mechanisms, and psychophysiological implications. *Psychophysiology*, *30*, 183-196.
- Bertson, G. G., Cacioppo, J. T., & Quigley, K. S. (1994). Autonomic cardiac control: I. Estimation and validation from pharmacological blockades. *Psychophysiology*, *31*, 572-585.
- Bertson, G. G., Cacioppo, J. T., Quigley, K. S., & Fabro, V. T. (1994). Autonomic space and psychophysiological response. *Psychophysiology*, *31*, 44-61.
- Binkley, P. F., & Boudoulas, H. (1986). Measurement of myocardial inotropy. In C. V. Leier (Ed.), *Cardiotonic drugs: A clinical survey* (pp. 5-48). New York: Marcel Dekker.

- Cacioppo, J. T. (1994). Social neuroscience: Autonomic, neuroendocrine, and immune response to stress. *Psychophysiology*, *31*, 113-128.
- Cacioppo, J. T., Bertson, G. G., Binkley, P. F., Quigley, K. S., Uchino, B. N., & Fieldstone, A. (1994). Autonomic cardiac control: II. Basal response, noninvasive indices, and autonomic space as revealed by autonomic blockades. *Psychophysiology*, *31*, 586-598.
- Cacioppo, J. T., & Tassinary, L. G. (1990). Inferring psychological significance from psychophysiological signals. *American Psychologist*, *45*, 16-28.
- Cacioppo, J. T., Uchino, B. N., & Bertson, G. G. (1994). Individual differences in the autonomic origins of heart rate reactivity: The psychometrics of respiratory sinus arrhythmia and pre-ejection period. *Psychophysiology*, *31*, 412-419.
- Coghill, R. C., Talbot, J. D., Evans, A., Meyer, E., Gjedde, A., Bushnell, H. C., & Duncan, G. H. (1994). Distributed processing of pain and vibration by the human brain. *Journal of Neuroscience*, *14*, 4095-4108.
- Danilova, N. N. (1995). Serdtschnyi ritm I informatsionnaya nagruzka [Heart rhythm and informational load]. *Vestn. Mosk. U-ta, Seria 14, Psikhologiya*, *4*, 14-27.
- Graham, F. K. (1979). Distinguishing among orienting, defensive, and startle reflexes. In H. D. Kimmel, E. H. van Olst, & J. F. Orlebeke (Eds.), *The orienting reflex in humans* (pp. 137-167). Hillsdale, NJ: Lawrence Erlbaum Associates.
- Graham, F. K. (1984). An affair of the heart. In M. G. H. Coles, J. R. Jennings, & J. A. Stern (Eds.), *Psychophysiological perspectives: Festschrift for Beatrice and John Lacey* (pp. 171-187). New York: Van Nostrand Reinhold.
- Graham, F. K., & Clifton, R. K. (1966). Heart-rate change as a component of the orienting response. *Psychological Bulletin*, *65*, 305-320.
- Grossman, P., Karemaker, J. K., & Wieling, W. (1991). Prediction of tonic parasympathetic cardiac control using respiratory sinus arrhythmia: The need for respiratory control. *Psychophysiology*, *28*, 201-216.
- Gulyas, B., Roland, P. E., Heywood, C., Popplewell, D. A., & Cowey, A. (1994). Visual form discrimination from luminance or disparity cues: Functional anatomy by PET. *Neuro-report*, *5*, 2367-2371.
- Harris, W. S., Schoenfeld, C. D., & Weissler, A. M. (1967). Effects of adrenergic receptor activation and blockade on the systolic pre-ejection period, heart rate and arterial pressure in man. *Journal of Clinical Investigation*, *46*, 1704-1714.
- Lacey, J. I. (1959). Psychophysiological approaches to the evaluation of psychotherapeutic process and outcome. In E. A. Rubinstein & M. B. Parloff (Eds.), *Research in psychotherapy* (pp. 160-208). Washington, DC: American Psychological Association.
- Lacey, J. I., Kagan, J., Lacey, B., & Moss, H. A. (1963). The visceral level: Situational determinants and behavioral correlates of autonomic response patterns. In P. H. Knapp (Ed.), *Expression of the emotions in man* (pp. 161-196). New York: International Universities Press.
- Lewis, R. T., Leighton, R. F., Forester, W. F., & Weissler, A. M. (1974). Systolic time intervals. In A. M. Weissler (Ed.), *Non-invasive cardiology* (pp. 301-368). New York: Grune & Stratton.
- Pavlov, I. P. (1927). *Conditioned reflexes*. New York: Oxford University Press.
- Quigley, K. S., & Bertson, G. G. (1990). Autonomic origins of cardiac responses to nonsignificant stimuli in the rat. *Behavioral Neuroscience*, *104*, 751-762.
- Richardson, R., Siegel, M. A., & Campbell, B. A. (1988). Unfamiliar environments impair information processing as measured by behavioral and cardiac orienting responses to auditory stimuli in preweaning and adult rats. *Developmental Psychobiology*, *21*, 613-633.
- Saters, J. A., Richardson, R., & Campbell, B. A. (1990). Disruption and recovery of the orienting response following shock or context change in preweaning rats. *Psychophysiology*, *27*, 45-56.

- Sloan, R. P., Shapiro, P. A., Bagiella, E., Fishkin, P. E., Gorman, J. M., & Myers, M. M. (1995). Consistency of heart rate and sympathovagal reactivity across different autonomic contexts. *Psychophysiology*, 32.
- Sokolov, E. N. (1963). *Perception and the conditioned reflex*. Oxford: Pergamon.
- Sokolov, E. N. (1994). Vector coding in neuronal nets: Color vision. In K. H. Pribram (Ed.), *Origins: Brain and self-organization* (pp. 463-475). Hillsdale, NJ: Lawrence Erlbaum Associates.
- Sokolov, E. N. (1995). Printsip vektornogo kodirovaniya v psikhofiziologii [Principle of vector coding in psychophysiology]. *Vestn. Mosk. U-ta, Seria 14, Psikhologiya*, 4, 3-13.
- Sokolov, E. N., & Vaitkavicius, G. G. (1989). *Neurointellct: Ot netrona k neirokompiutru* [Neurointelligence: From neuron to neurocomputer]. Moscow: Nauka.
- Tulving, E., Markowitsch, H. J., Kapur, S., Habib, R., & Houle, S. (1994). Novelty encoding networks in the human brain: Positron emission tomography data. *NeuroReport*, 5, 2525-2528.
- Turpin, G. (1986). Effects of stimulus intensity on autonomic responding: The problem of differentiating orienting and defense reflexes. *Psychophysiology*, 23, 1-14.

Orienting, Habituation, and Information Processing: The Effects of Omission, the Role of Expectancy, and the Problem of Dishabituation

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Orienting and habituation have been important topics of investigation for over two decades. Initial interest following Sokolov's (1960, 1963) early publications stemmed from the fact that the sensitivity of orienting to stimulus change seemed to carry implications for how sensory information was coded and processed. Orienting and habituation have now come to occupy a central position in the work of many behavioral scientists and neuroscientists for at least three reasons. First, orienting seems to be related to attentional processes, especially those processes that underlie passive attention to input (Graham & Hackley, 1991; Pavlov, 1927). This means that orienting can be used to study attention itself and to study attentional dysfunction in clinical or subclinical groups (e.g., Bernstein, 1992; Dawson, Nuechterlein, Schell, Gitlin, & Ventura, 1994). Second, habituation is an important aspect of behavioral plasticity (Groves & Thompson, 1970), and third, orienting and habituation can be observed across a wide range of vertebrate and invertebrate species and in a variety of response systems (see Campbell, Wood, & McBride, chapter 3, this volume). For these reasons, orienting and habituation have been subjected to intensive investigation, not only in their own right, but also in connection with theory development in areas such as cognitive development (Graham, Anthony, & Zeigler, 1983), associative learning (Pearce & Hall, 1980, 1992; Wagner, 1978), information processing (Ohman, 1979; Siddle & Spinks, 1992), psychopathology and emotion (Bernstein, 1992; Ohman,