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The Role of Interoception in Learned Visceral Control

Linda Gannon[1]
University of Southern Illinois, Carbondale

Research concerned with the psychology and physiology of interoceptive processes is reviewed with the purpose of evaluating theoretical formulations of learned visceral control. Basic animal research in interoception provides relevant information; however, much research dealing directly with interoception and learned control is inadequate due either to inappropriate measurement of interoceptive ability or to poor experimental design. The two primary theoretical orientations linking interoception and learned visceral control differ according to the role ascribed to external feedback; the first views feedback as an enhancement of interoceptive cues, the second as an enhancement of exteroceptive cues. These theories are discussed with regard to recent investigations of learned visceral control.

In the last decade, learned control of visceral functions utilizing biofeedback techniques has been a popular and interesting area of research in terms of both theoretical and clinical applications. Early research dealt primarily with the demonstration of the phenomenon; only recently have there been attempts to form theoretical contexts within which the research can be integrated and hypotheses generated. Interoception plays a major role in several theories that have been developed in order to explicate the relationship between biofeedback and voluntary control. The purpose of this paper is to integrate physiological and psychological research dealing with interoception and to evaluate interoceptive theories of biofeedback in light of recent research.

[1]Address all correspondence to Linda Gannon, Department of Psychology, University of Southern Illinois, Carbondale, Illinois 62901.

INTEROCEPTION

The medical literature offers differing definitions for the term *interoception*. In this paper, *interoceptors* refer to those receptors that initiate impulses from the viscera, which include, but are not limited to, the gastrointestinal, cardiovascular, urogenital, and respiratory systems. *Interoception* refers to the generation and conduction of visceral impulses along afferent nerves to the central nervous system. Initially, the viscera were thought to have only efferent innervation; therefore, the existence and functional characteristics of interoceptors and visceral afferents have been relatively recent interests. A brief and selective review to acquaint the reader with the different areas of research relevant to interoception is presented below.

Psychologists have long been interested in the *idea* of the human consciousness receiving and using information from the viscera. As early as 1922, William James formulated a theory of emotion which stated that the mental experience of emotion *was* the visceral and somatic state of the organism. He hypothesized two possible mechanisms: Either the viscera produce sensations that are perceived by consciousness, or our consciousness is aware of centrally initiated impulses that affect the viscera. James preferred the former conception although this necessitated the assumption that the viscera were supplied with afferent nerves, which, at that time, had not been demonstrated. More recently, Schacter and Singer (1962) presented evidence suggesting that the labeling of a particular reaction (euphoria, anger) is due to the cognitive interpretation of the external situation when the person is experiencing physiological arousal—again, the theory requires the assumption that persons are able to perceive visceral events.

Lacey (1967) has done extensive research on phasic heart rate responses. His results have consistently shown heart rate decelerations to tasks requiring maximal sensitivity to the environment, such as responding to a signal stimulus, and heart rate accelerations to tasks requiring cognitive elaboration and reduction of extraneous stimulation, such as math problems. In interpreting these data, Lacey assumes that the heart rate response initiates a facilitatory reflex whereby heart rate increases inhibit cortical and muscular activity and heart rate decreases produce cortical arousal and increased muscle tone. He further assumes that these reflexes are mediated by the baroreceptors and baroreceptor afferent fibers. Visceral afferentation is thus a vital link in the theories described above. Although this research merely suggests the existence of afferent mechanisms, it does demonstrate the continuing relevance of interoception to psychological theory.

More direct evidence comes from Russian classical conditioning studies that have demonstrated that stimulation of interoceptors (distention of the renal pelvis, the lumen of the viscus, or the carotid sinus in animals) can function as conditioned stimuli and that differential conditioning between ileal and cecal distentions is possible (Chernigovskiy, 1967). As Razran (1961) points out, if either the conditioned stimulus or the conditioned stimulus and the unconditioned stimulus are stimuli delivered directly to a specific viscus, then, for conditioning to occur, the viscera must initiate afferent impulses. Further evidence of visceral afferentation comes from electroencephalographic changes in response to stimulation of the viscera—cortical desynchronization results from renal distention (Adam, 1967) and cortical synchronization results from carotid distention (Bonvallet, Dell, & Hiebel, 1954). Adam (1967) states: "An increasing number of observations point to the circumstance that visceral functions are represented on each level of the central nervous system, from medulla to cortex . . ." (p. 53).

The interoceptors of most relevance to this paper are those which influence cardiovascular functioning. Interoceptors are present in the carotid sinus, aortic arch, atria, and the ventricles and are sensitive to either mechanical distention due to blood volume changes or chemical aspects of the blood (Milnor, 1974). These receptors have been anatomically identified and studied according to morphological and histochemical techniques (Pletchkova & Khaisman, 1976). Electrical stimulation techniques have been utilized to study the firing characteristics and reflex effects in animals. Both vagal and sympathetic afferents have been studied; the former tend to be tonically active and when stimulated result in cardiac slowing, while the latter tend to be normally silent and when stimulated result in cardiac speeding (Oberg, 1976). Thus, physiologists have gone beyond establishing the mere existence of interoceptors and visceral afferents and are studying the intricacies of their functioning.

The existence of afferent visceral innervation does not necessarily lead to the conclusion that humans have the potential to be aware of specific visceral functions. Chernigovskiy (1967) has observed that a relatively small area of the cortex is devoted to analyzing visceral functions compared to visual and auditory analyzers. Thus, interoception may lack the fine discrimination of exteroception. In addition, visceral information may not be discriminable from somatic information. At all levels of the central nervous system, there is rather close overlapping of the pathways and representation zones of visceral and somatic functions. Chernigovskiy (1967) reported a study that demonstrated that vagal afferent impulses did not result in a cerebellar response if impulses were sent from the nerves of the skin 30 milliseconds prior, indicating that in some instances, visceral and somatic impulses are addressed to the same neuron. To summarize, the evidence presented above indicates that the autonomic nervous system is indeed supplied with afferent nerves; however, both the possible lack of "fine tuning" in the visceral system and the apparent overlap between the visceral and somatic innervation systems may place a physiological limit on the specificity of interoception.

INTEROCEPTION AND LEARNED VISCERAL CONTROL

Research concerned with the interoceptive abilities in humans has been primarily in the context of visceral learning. Publications documenting the afferentation of the autonomic nervous system (Chernigovskiy, 1967; Adam, 1967; Oberg, 1976) and claims of instrumental conditioning of autonomic functions (Miller, 1969) both occurred in the late sixties and together formed the basis for an interoceptive theory of learned autonomic control. Briefly, the theory states that the facilitating effect of external feedback on the learned control of the viscus is mediated by enhanced awareness of internal cues. In other words, when external feedback coincides with naturally occurring afferent information, persons can learn to recognize and direct their attention to interoceptive cues and thus become "aware" of their ongoing visceral activity. This awareness can then be utilized to inform the person if he/she is producing the instructed heart rate changes. Several empirical hypotheses are logical consequences of this theory: If external feedback improves instructional control of the viscus by increasing awareness of visceral cues, then (1) it should be possible to demonstrate increased awareness resulting from external feedback, and (2) performance on an awareness or interoceptive task should correlate positively with performance on an instructional control task. Research attempts to test these hypotheses have dealt primarily with heart rate and heart period. This research is summarized and critically evaluated below.

Effects of External Feedback on Cardiac Awareness

An important consideration in evaluating the research concerned with defining the relationship between external feedback and interoception is the method employed to assess interoception. Interoceptive tasks can be categorized into two broad categories: (1) production tasks where subjects are required to continuously initiate motor responses according to their perception of heart rate or heart period, and (2) discrimination tasks where subjects attend to a visual, auditory, or tactile representation of either their cardiac activity or a similar presentation generated by a source other than their immediate cardiac activity; at the end of a specified period of time, subjects are required to indicate if the stimuli had been generated by their cardiac activity or by the other source.

Brener (Note 1) was the first to report results on a discrimination task. In this study, one group was required to discriminate between their immediate heart rate and a regular clock pulse (frequency equal to average heart rate) delivered as vibratory stimuli to the wrist, and another group was required to discriminate between their prerecorded heart rate and a regular clock pulse. The purpose of the second group was to eliminate the possible interpretation that subjects were basing their discriminations on regular versus irregular stimuli. Only the experimental group showed a significant increase in percent correct trials (20 trials) from pre- to posttraining. The training trials were similar to test trials but subjects were informed of the correctness of their decisions. The authors concluded that the individuals in the experimental group were basing their discriminations on "interoceptive events uniquely associated with cardiac action."

Gannon (Note 2) employed a discrimination task that required subjects to discriminate between their immediate heart rate and their prerecorded heart rate. Cardiac activity was displayed on a computer-slaved scope; a horizontal line moved across the scope and terminated with the heartbeat, after which another horizontal line began immediately; thus, heartbeats coincided with line terminations and the length of the line was proportional to the R—R interval. With the aid of an intercom and an identical scope that the experimenter observed, it was discovered that those subjects who learned to make the discrimination did so by coughing, sighing, holding their breath, or yawning and then watching for the unconditioned cardiac effects of these maneuvers. In addition, those subjects who had previously learned their sinus arrhythmic pattern showed near-perfect performance on the discrimination task. In Brener's study, the experimental group had the opportunity to employ similar cues while the control group did not, which could explain his results. Therefore, it appears that the discrimination tasks described above are inadequate as a measure of cardiac interoception since good performance can be easily achieved in the absence of perception of visceral cues.

Production tasks require that persons continuously *produce* responses in accord with their cardiac perception rather than *recognize* an external representation of their cardiac activity. These tasks are not, therefore, liable to the same criticisms as discrimination tasks. Several types of tasks have been used to demonstrate or test interoception. Kleinman (Note 3) and McFarland (1975) required that subjects press a button in rhythm with their perceived heartbeats. Donelson (Note 4) had subjects control a potentiometer, which controlled the trigger rate of an oscilliscope; the subjects were to match the trigger rate with their perceived heart rate. Gannon (Note

2) used a task where the subjects controlled the termination of successive moving horizontal lines with the goal that the termination coincided with a heartbeat and the length of the line was proportional to the R—R interval. Production tasks seem to be preferable to discrimination tasks in testing interoceptive ability because they are less amenable to success through the utilization of irrelevant cues.[2]

Research studies designed to evaluate the effects of feedback on cardiac interoception have typically tested the subjects' heart rate awareness, then presented beat-by-beat feedback, and then retested awareness. However, the result of improvement from the first test to the second test is amenable to interpretations other than learned awareness. For example, on the pretraining test of tapping in rhythm to heart rate a subject may tap at a constant rate of 50 bpm. After listening to auditory feedback of a short tone presented at every beat, the subject may (if average heart rate is 70 bpm), on the posttraining test, tap at about the same rate as the feedback. In addition, the subject may become sensitized to the variations in heart rate associated with respiration and may be able to reproduce the sinus arrhythmic pattern during the second test. Learning the general rate and sinus arrhythmic characteristics would improve the subject's score but this would not necessarily reflect improved interoception. Thus, in order to evaluate the effects of feedback on interoception, one must control for the possibility that improved performance on an awareness task could result from the learning of noninteroceptive cues. In the studies that follow, Brener employed a statistical control while Gannon attempted to experimentally control for this problem.

Brener (1974) reports a study in which experimental subjects heard a tone at each R-wave during feedback trials and were then required to press a button at each heartbeat during test trials. The author states that simply comparing the number of button presses to the number of heartbeats was an inappropriate method of data analysis because apparent learning could be a reflection of the subject learning to press the button at approximately the same rate as his/her heart. He attempted to control for this problem statistically by a scoring procedure involving a latency criterion between heartbeat and button press in order to score as correct only those presses that

[2]A further difficulty in assessing cardiac awareness that applies to both discrimination and production tasks is the possibility that subjects may rely on exteroceptive sensory input to perform the task. This problem can be partially alleviated by instructing subjects not to feel their pulse and by observing them to ensure that they follow instructions. Other forms of exteroceptive information, such as pressure changes in the ear or at the temple accompanying cardiac systole, would be impossible to eliminate in an intact organism. Since people rarely, if ever, perform perfectly on the tasks mentioned, it is unlikely that accurate exteroceptive information is continuously available. However, caution should be exercised in data interpretation since it is possible that feedback acts to enhance exteroceptive, rather than interoceptive, cues.

were clearly a response to a particular heartbeat and thus provide a measure of beat-by-beat perception rather than only general rate perception. Control subjects heard an irregular sequence of tones during feedback and were required to reproduce the pattern during test trials. Experimental subjects did show significant improvement whereas the control group did not. However, the control group was not instructed to press the button in response to heartbeats. Thus, the improvement of the experimental group could just as easily be attributed to practice effect or to a set to perceive cardiac activity as to feedback.

Gannon (Note 2) utilized an experimental design that included several control groups in order to estimate the amount of postfeedback awareness due to learning information irrelevant to interoception. The type of feedback was varied in such a way as to provide either beat-by-beat, variability, level, or sinus arrhythmic information to the subject, and instructions to the subjects emphasized and directed attention to the information available in the feedback. Cardiac awareness was assessed before and after feedback trials. It was hypothesized that if external feedback has a facilitating effect on cardiac awareness, then the group receiving beat-by-beat information would show the most awareness. The variance analysis indicated that the group receiving beat-by-beat feedback was better at heart rate estimation than the other groups, although these results must be interpreted with caution due to initial group differences. Within-group correlations suggested that there were qualitative, as well as quantitative, learning differences among the groups. The group that received beat-by-beat feedback and instructions to attend to interoceptive cues seemed to rely on their perception of internal cues in order to perform the awareness task while the other groups relied on other aspects of the feedback, such as learning their sinus arrhythmic pattern, in order to perform the awareness task. Certainly more research is needed in this area; however, the evidence available suggests that external feedback does encourage learned recognition of internal cues.

Effects of Cardiac Awareness on Cardiac Control

An evaluation of the interoceptive theories of cardiovascular biofeedback requires an analysis not only of the relationship between feedback and interoception but also of the relationship between interoception and voluntary control. Keeping in mind the criticisms stated above of the methodology used to assess awareness, it is appropriate at this point to review the literature relating cardiac interoception and cardiac control.

In the study cited above by Brener (1974) both the experimental (trained in interoception) and control groups were instructed to increase and decrease their heart rate subsequent to interoceptive training; the experimental group demonstrated significantly better heart rate control than the control group. However, the interpretation of these results is questionable since the experimental group was not necessarily superior in interoceptive ability (see above) and since the difference in control ability between the groups could be explained in terms of amount of feedback as well as degree of awareness.

McFarland (1975) provided heart rate feedback for 30 seconds, then tested awareness with a button-press task and developed an awareness score based on the percentage of heartbeats perceived. Correlations were computed between these scores and scores of increasing and decreasing performance. Awareness and decreasing were not correlated but awareness and increasing were significantly and positively correlated. However, this study has methodological problems. Subjects were informed prior to baseline assessment which task (increasing or decreasing) they would be asked to perform. This could have affected basal heart rates, which in turn could have contributed to performance scores atypical of this type of task. Only 11 of 21 subjects were able to increase their heart rate and the mean increase was 1.20 bpm. Generally, human subjects show much larger increases (Blanchard & Young, 1973).

In the study cited above by Gannon (Note 2), subjects were required to either increase or decrease their heart rate after the final test of cardiac awareness. Although there were significant group differences in cardiac awareness, these groups did not differ in their ability to control their heart rate in spite of the fact that typical increases (10 bpm) and decreases (3.5 bpm) were obtained. In addition, no correlations suggested a positive relationship between interoception and voluntary control. Both of the first two studies cited above have methodological problems rendering interpretation difficult. Subjects in the third study were successful in demonstrating both visceral control and visceral interoception but the data did not support either an experimental or a correlational relationship between the two skills. At this point in biofeedback research, there is no direct evidence to support the hypothesis that the feedback effects on voluntary control are mediated by interoception.

THEORETICAL IMPLICATIONS

The theoretical orientation of the studies cited above assumes that feedback provides awareness and awareness enables control. A logical corollary of this theory is that visceral control is ordinarily lacking in the human organism due to inadequate receptors, afferent pathways, and/or central nervous system analyzers involved in interoception. The assumption that humans lack adequate interoception leads to a theory of biofeedback control which ascribes the role of the feedback to one of enhancement of naturally occurring interoceptive feedback. According to this view, the difference between skeletal responses and visceral responses in the ease with which voluntary control is acquired is attributed to a difference in the quantity or quality of information conveyed from the periphery to the central nervous system. Indirect support for this theory is provided by the physiological evidence presented above, which indicates that little of the cerebral cortex is devoted to analyzing visceral afferents and that there is considerable overlap in both the central and peripheral nervous systems between visceral and somatic functions. This lack of "fine tuning" may necessitate improvement upon the naturally occurring visceral feedback in order to bring the responses under instructional control—the improvement being effected by external feedback. However, the research presented above does not support a covarying relationship between interoceptive ability and control ability and thus offers minimal supporting evidence for this theory.

Brener (1974) introduces an opposing theory of biofeedback which he refers to as "exteroceptive deafferentation." He suggests that the autonomic system has adequate interoception but inadequate exteroception. Exteroceptive deafferentation refers to the lack of stimulus consequences of a response. For example, raising one's arm results in proprioceptive feedback and, in addition, results in exteroceptive feedback; the position of the arm stimulates the visual apparatus, and visual exteroceptive information is conveyed to the central nervous system. In the visceral system, there are no apparent response consequences that could serve as exteroceptive stimulation. Brener suggests that it is this lack of exteroceptive feedback that prevents instructional control of visceral responses under ordinary circumstances and that biofeedback provides this necessary information. He adds that in both visceral and skeletal responses, the exteroceptive feedback does not substitute functionally for interoceptive feedback but rather "calibrates the intrinsic feedback in terms of an external referent" (p. 374). After calibration has occurred, the voluntary nature of the response can be maintained in the absence of exteroceptive feedback as long as adequate interoceptive feedback is present. This view, if correct, offers encouragement for successful clinical applications of biofeedback; it promotes the expectation that patients can generalize laboratory learning to environmental situations.

According to this theory, biofeedback is conceptualized as exteroceptive feedback, that is, as having a role functionally similar to that of visual feedback for skeletal movements. The research presented in the sections above does not directly address this theory. For example, one would not expect feedback presented during normal resting levels to affect control performance; in order for calibration to occur, feedback must be presented during the desired response (in the examples above, increasing or decreasing heart rate). Indications that calibration has occurred might be a demonstrated ability to accurately detect level or tonic changes, as opposed to phasic changes, which would indicate learned interoception, or another indication of calibration might be the ability to produce the desired response in the absence of feedback.

A logical extension of this theory is that the basic difference between skeletal and visceral responding is that there is naturally occurring exteroceptive feedback in the former but not the latter. Therefore, if exteroceptive feedback (biofeedback) were provided for visceral responses, then one would expect visceral behavior to obey learning principles similar to those of skeletal behavior. Lang and his associates have done a series of studies investigating the utility of viewing visceral learning as analogous to the learning of a complex motor skill. Their results for heart rate are briefly summarized: (1) Analogue feedback of performance is superior to binary, and responses learned during feedback do, to some extent, transfer to non-feedback situations (Lang & Twentyman, 1974); (2) beat-by-beat feedback is superior to feedback provided less frequently (Gatchel, 1974); (3) performance improves over trials, and performance can be enhanced by providing monetary incentives (Lang & Twentyman, 1976). (In general, these results were striking for speeding and less apparent for slowing responses.) These results are those one would expect if the desired response were a skeletal one. Apparently then, the development and maintenance of voluntary responses of the visceral system parallel those processes, at least in some respects, of the skeletal system provided that exteroceptive feedback is available.

In conclusion, the two theories relating interoception and biofeedback differ according to the role that is ascribed to the feedback. The theory based on "interoceptive deafferentation" requires the assumption that naturally occurring interoception is inadequate and biofeedback serves the purpose of augmenting interoception. Researchers investigating interoception have concentrated their efforts on testing hypotheses related to this theory and have found little supporting evidence. The second theory based on "exteroceptive deafferentation" assumes naturally occurring interoception is adequate but exteroception is lacking for visceral responses and necessary for the development of voluntary control. According to this theory, the role of biofeedback is to provide exteroceptive feedback. Although the research based on a motor skills approach is certainly relevant to and provides support for this theory, a more direct testing of basic assumptions and hypotheses is needed.

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