PSYCHOPHYSIOLOGY
Vol. 13, No. 1
Printed in U.S.A.

Patterns of Cerebral Lateralization During Cardiac Biofeedback versus the Self-Regulation of Emotion: Sex Differences

RICHARD J. DAVIDSON AND GARY E. SCHWARTZ
Department of Psychology and Social Relations, Harvard University

ABSTRACT

The purpose of the present study was twofold: (1) to obtain information on central mechanisms underlying cardiac self-regulation by comparing changes in cerebral asymmetry during self-control of heart rate with changes observed during the production of affective imagery; and (2) to explore sex differences in hemispheric function during performance of these two tasks. Heart rate (HR) and bilateral parietal EEG filtered for alpha were recorded from 20 right-handed males and females during two discrete experimental phases: cardiac control and image self-generation. HR showed significant effects between up versus down in prefeedback and feedback, and between anger versus relaxing imagery in the image phase. The EEG data indicated similar patterns of hemispheric asymmetry in both sexes during prefeedback. However, with the introduction of feedback, females shifted to greater relative right hemisphere activation comparable to what they show when specifically instructed to think emotional thoughts; males showed little differentiation between conditions. These data indicate that the self-regulation of HR with biofeedback in males and females may be accomplished by the utilization of strategies involving different underlying patterns of neuropsychological processes.

DESCRIPTORS: Cardiac control, Cerebral lateralization, Self-regulation, Biofeedback, Sex differences, Emotion.

When subjects are given instructions and feedback for heart rate changes, they can rapidly learn to both increase and decrease their heart rate (Blanchard & Young, 1973). Interestingly, subjects typically employ combinations of different strategies while engaged in these tasks. For example, Bell and Schwartz (1975) have reported that thoughts and feelings of excitement, sex, fear, and tension predominated during trials in which subjects were specifically instructed to increase their heart rate. Alternatively, subjects reported feelings of relaxation, tranquility, and contentment during instructed heart rate decrease trials.

These subjective reports reflect different combinations of cognitive, affective, and somatic strategies. Davidson and Schwartz (in press) have recently illustrated the importance of distinguishing between such strategies in self-regulation techniques, since their differential utilization is often consequential in predicting the psychophysiological changes elicited. For example, contrary to what might be initially expected on the basis of the association of the cardiovascular system with emotion, subjects simply instructed to "control and raise" their heart rates in the absence of feedback, increase their heart rates significantly more than a group specifically told to "make themselves aroused" by thinking sexual, angry, and related thoughts (Bell & Schwartz, 1973). The differences between these groups were preserved and accentuated when biofeedback was introduced. Based upon the important association between heart rate and somatic activity (Obrist, Howard, Lawler, Galosy, Meyers, & Gaebelein, 1974), Bell and Schwartz suggest that the "control and raise" instructions initiated somatic activity which affected heart rate through central and peripheral mechanisms, while the imagery instructions, by demanding attention to cognitive events, may have reduced the generation of motor activity, thereby

This research was supported in part by an NSF pre-doctoral fellowship to R.J.D. and by the Advanced Research Projects Agency of the Department of Defense and monitored by the Office of Naval Research under Contract N00014-70-C-0350 to the San Diego State University Foundation to G.E.S.

Address requests for reprints to: Richard J. Davidson, Department of Psychology and Social Relations, Harvard University, 1184 William James Hall, Cambridge, Massachusetts 02138.

attenuating the magnitude of self-regulated heart rate increases.

Recent research has begun to focus upon the central neuropsychological mechanisms subserving somatic and affective processes, particularly left-right lateralization involved in their generation. In a study employing lateral eye movements as an index of hemispheric activation, Schwartz, Davidson, and Maer (1975) have reported that affectively laden questions elicit significantly fewer right eye movements and more left movements than comparable non-emotional questions, a pattern indicative of greater right hemispheric participation in this affective task. Other investigators, employing widely divergent methodologies, have also found affective processes to be more subserved by the right hemisphere. For example, Gainotti (1972) compared patients with unilateral left and right hemisphere lesions on their affective response to their illness. He observed that those patients with an intact right hemisphere and a lesioned left hemisphere predominantly manifested a "catastrophic" response to their illness while those patients with the opposite lesion pattern typically expressed indifference over their condition, a pattern indicative of greater right hemisphere involvement in emotion. Similarly, Wechsler (1973) has found that patients with right hemisphere lesions were significantly impaired on memory for affective verbal material relative to non-affective verbal material. Using dichotic listening procedures in normal subjects, Carmon and Nachson (1973) found a small, but significant left-ear superiority for emotional vs non-emotional verbal material.

On the other hand, Kimura and Archibald (1974) have found that the production of somatic activity in the form of motor sequences was more under the control of the left hemisphere. They observed that patients with unilateral left hemisphere lesions were significantly impaired relative to patients with comparable right hemisphere lesions on tasks involving the copying of novel hand movements, and this impairment was significant for both hands. These investigators conclude that their data "support and extend Liepmann's (1908) contention that the left hemisphere has important functions in motor control, not shared by the right hemisphere [p. 346]." The hypothesis of greater left hemisphere participation in motor control has recently been confirmed and extended by a variety of clinical observations by Geschwind (1975).

The primary purpose of the present experiment was to obtain information on central mechanisms underlying cardiac self-regulation by recording bilateral EEG, which in previous research has been shown to be sensitive to covert cognitive strategy (e.g. Robbins & McAdam, 1974; Galin & Ornstein, 1972), during cardiac self-regulation compared with the self-generation of emotion using affective imagery. In addition, the study was designed to explore sex differences in hemispheric function during the performance of these two tasks since a variety of evidence has been gathered indicating differential cerebral lateralization between the sexes (reviewed by Buffrey & Gray, 1972). We specifically hypothesized that females would show greater task dependent shifts in EEG asymmetry than males (see Davidson, Schwartz, Pugash, & Bromfield, Note 1).

Method

Subjects

Twenty right-handed college students, 12 males and 8 females, were employed as subjects. All were paid volunteers and in good health.

Apparatus and Recording Procedures

Bilateral EEG was recorded from the left and right parietal areas (P_3 and P_4) referenced to a common vertex (C_z) (Jasper, 1958) with Beckman miniature electrodes. All measures were recorded on a Grass Model 7 polygraph and each EEG channel was filtered for 8–13Hz activity and displayed on two additional channels individually calibrated to yield a pen deflection of 1.5 cm for an average peak alpha burst. Grason-Stadler logic modules were employed to detect and automatically count bursts of criterion alpha on line. An arbitrary criterion of .5 cm was utilized so that alpha activity had to be at least 33.3% of the average peak amplitude to be counted. Bursts of 4 alpha waves within a maximum of .5 sec were required to activate the counter and constituted one alpha unit; this effectively removed any movement artifact from being counted as alpha, and provided a reliable, conservative measure of alpha activity. Heart rate was recorded arm-to-arm using standard EKG plate electrodes. Logic modules were programmed to automatically detect and count the R wave of each cardiac cycle. Cardiotachometer output displaying beat by beat changes in heart rate was recorded on an additional channel.

Procedure

Subjects were employed in a repeated-measures design with two discrete experimental phases. During the cardiac control phase, subjects were first given the instruction to increase and decrease their heart rate in the absence of overt somatic or respiratory maneuvers, for 2 1-min trials in each direction without feedback and subsequently for 4 1-min trials in each direction with simple auditory biofeedback—a 100 msec tone presented through a loudspeaker in front of the subject concomitant with each heart beat. One-min rest periods in the absence of feedback were interspersed between every 2 heart rate control trials and order of trials was counterbalanced within and across subjects. In the image phase of the experiment, subjects were requested to self-induce covert affective and non-affective states using either verbal or visual strategies, in 2-min trials. Four affective and 4 non-affective trials were presented in counterbalanced order with 2 2-min rest periods interspersed between them. During the emotional trials, subjects were asked, in separate trials, to actively "relive the feelings" from angry and relaxing scenes from their past which, in a pre-experimental questionnaire, they had rated as being "very intense" (ratings of 4 or 5 on a five-point scale). Half of the emotional trials required reliving anger and the remaining trials required the re-experiencing of relaxation-contentment. During half of these trials (counterbalanced across emotions) subjects were asked to utilize verbal imagery (i.e., "write a letter to friend covertly about the events surrounding your experience") while the remaining affective trials required the utilization of visual imagery ("picture the events surrounding your experience"). During half of the non-emotional trials, subjects were required to simply "think about a typical day from the time you wake up to the time you go to sleep" using either verbal or visual strategies (in separate trials). For the remaining 2 non-affective trials subjects were requested to perform a covert verbal task ("think of as many words as you can beginning with the letter 'h'") and a covert visual task ("picture as many different buildings from the Boston area as you can"). Half the subjects were randomly assigned to the cardiac control phase first, while the remaining subjects received the image phase first. All trials were performed with eyes closed.

Data Analysis

Heart rate was analyzed in bpm and averaged within all up, down, and rest trials during the cardiac control phase and across the verbal and visual relaxation and verbal and visual anger conditions during the affect self-generation phase.

EEG data for all experimental trials were evaluated by computing the ratio of the percentage of resting alpha activity in homologous right and left leads—right parietal alpha for task trials divided by right mean rest over left parietal alpha divided by left mean rest (P_4 task/P_4 rest)/(P_3 task/P_3 rest). The rest trials used to calculate these ratio scores were those that surrounded the particular blocks of trials in question, i.e., the mean resting values for the prefeedback, feedback, and affect phases. This ratio score serves to "correct" the obtained values for individual differences in resting alpha activity. Higher ratio values are indicative of greater relative left hemisphere activation. Three way analyses of variance with Condition (prefeedback, feedback, and affect) and Direction (up-down and anger-relaxation) as repeated factors and Sex as a between groups factor were separately performed for heart rate and EEG ratios. Two-tailed t-tests were employed to assess the significance of individual comparisons when a significant F was obtained. Unless otherwise indicated, the rejection region is $p<.05$ throughout.

Results

Heart Rate Control

The heart rate data are presented in Fig. 1. Analysis of variance revealed a highly significant main effect for Direction (up vs down and anger vs relaxation, $F(1/18)=102.54$, $MS_e=1443.72$) as well as a significant Direction × Condition interaction ($F(2/36)=23.00$, $MS_e=163.52$). During pre-feedback, with simple instructions to raise and lower their heart rate, subjects showed a highly significant difference of 5.98 bpm between up versus down trials ($t(19)=7.058$). Heart rate during prefeedback up was significantly higher than during rest (+4.53 bpm) ($t(19)=3.728$), and down was significantly lower than prefeedback rest (−1.45 bpm) ($t(19)=2.30$). The difference between up

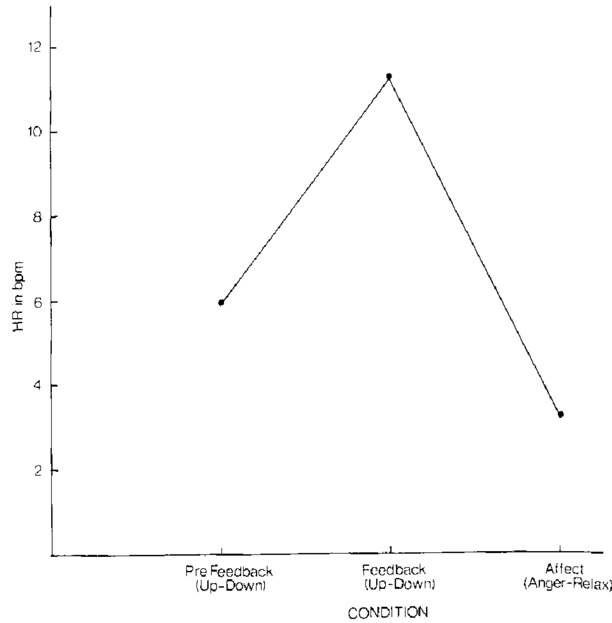

Fig. 1. Mean difference in heart rate in bpm between up vs down trials for prefeedback and feedback and between anger vs relaxation trials for affect. All means are based upon 20 subjects.

versus down increased significantly to 11.39 bpm during feedback ($t(19)=5.280$), indicating enhanced heart rate control. Both the up versus down and up versus rest effects (+10.06 bpm) were significant ($t(19)=9.312$; $t(19)=6.900$), whereas the down versus rest (−1.35 bpm) change failed to reach significance. There were no significant sex differences in heart rate control.

Heart rate during the emotion conditions produced a significantly smaller effect of 3.31 bpm between anger vs relaxation compared to prefeedback up vs down ($t(19)=2.529$). Mean heart rate during anger trials was significantly higher than during relaxation trials ($t(19)=4.15$); mean heart rate during the anger trials was significantly higher than during rest (+3.7 bpm) ($t(19)=3.55$), while the difference between relaxation versus rest failed to reach significance (+0.38 bpm). The attenuated HR effect for affective imagery instructions compared to biofeedback "control and raise" instructions replicates the prior findings of Bell and Schwartz (1973). Again, there were no significant sex differences in heart rate during the emotion conditions.

EEG Ratios

To examine the basic laterality effect involving the comparisons of biofeedback control with affect self-generation, the EEG ratio scores were first collapsed across up and down trials. It was reasoned that both in biofeedback control and affect self-generation, components of the central mechanisms subserving the utilization of different strategies would probably be similar (though not necessarily identical) despite the direction of HR change. For example, the self-generation of anger or contentment both involve the control of affect; if affect does indeed differentially involve the right hemisphere, its activation should reflect the elicitation of affective processes generally.[1] Similarly, the control of somatic processes, whether in the direction of tension or relaxation, involves the manipulation of motor behavior which has previously been found to predominantly engage the left hemisphere.

EEG ratios averaged across up and down trials during prefeedback and feedback and across anger and relaxation trials during affect self-generation for the entire group were first compared. Although the group means suggested differences ($\bar{X}$ ratio for prefeedback = 1.070; for feedback = 1.037; for affect = 0.996), the main effect for Condition was not significant ($F(2/36)=1.13$, $MS_e=0.53$). However, a separate analysis of variance on the covert image phase of the experiment revealed, as predicted, a significant main effect for Emotion ($F(1/18)=7.75, MS_e=0.96$). This indicates that the self-generation of affective imagery is associated with significantly greater relative right hemisphere activation compared with non-affective imagining. These data provide the first demonstration of right hemisphere specialization for emotion in the intact human using bilateral EEG as a dependent measure. Although the means for the verbal and visual main effects are in the predicted direction ($\bar{X}$ verbal = 1.053; $\bar{X}$ visual = 1.011), the main effect for mode failed to reach significance. This lack of a main effect for modality of imagery can probably be accounted for by the ineffectiveness of the manipulation. Seventy percent of the subjects spontaneously reported that it was extremely difficult to perform the verbal emotional trials and the verbal neutral day trial in the absence of visual imagery. Since other investigators have reported that covert visual imagery elicits relative right hemisphere activation (Robbins & McAdam, 1974), it is not surprising that we did not find significant differences in asymmetry between conditions.

Sex differences were next examined. A main effect for Sex was obtained ($F(1/18)=4.54$, $MS_e = .22$) with males showing a higher ratio than females ($\bar{X}$ ratio for males = 1.078; for females = .990). EEG ratios during prefeedback, feedback, and affect conditions split by sex are illustrated in Fig. 2. As predicted, a significant Sex × Condition interaction was obtained ($F(2/36)=4.24$, $MS_e= .20$.[2] During feedback, there were no significant sex differences in EEG ratios. However, when feedback was introduced, females showed significant relative right hemispheric activation when compared to males ($t(18)=2.317$). This effect is primarily due to a significant relative right hemispheric shift from prefeedback to feedback for the females ($t(7)=2.729$). Although males showed a slight increment in relative left activation from prefeedback to feedback, this difference was not significant.

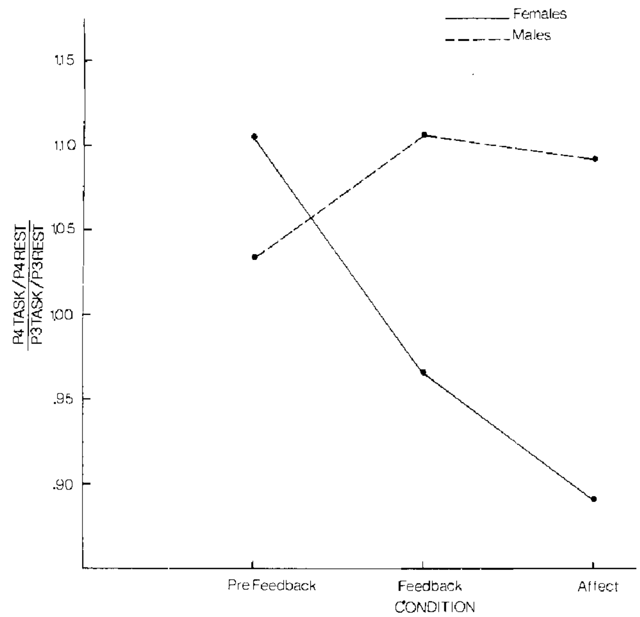

Fig. 2. Mean EEG alpha ratio score for males (N=12) and females (N=8) during prefeedback and feedback conditions averaged across up and down trials and during the affect condition averaged across anger and relaxation trials.

A comparison between hemispheric activation during the cardiac control phase and the covert

[1]Few investigators have attempted to provide a rationale for greater right hemisphere involvement in emotion. However, a possible clue might be gleaned from a comprehensive review of the mechanisms of hemispheric specialization by Semmes (1968) where it was suggested that the right hemisphere is diffusely organized with various functions having overlapping representations. We would like to tentatively propose that since emotion typically involves the integration of heteromodal or unlike inputs (e.g. cognitive and visceral), it would appear, based on the available evidence, that the right hemisphere is uniquely suited to perform such a task.

[2]To ascertain whether the main effect for Sex and the Sex × Condition interaction were a function of any changes in resting EEG asymmetry from one phase to the next, the identical comparison was performed on the ratio of the difference in alpha units between P_4 minus P_3 over the sum of alpha at P_3 and P_4 (R−L/R+L). As was found with the resting ratio employed above, analysis of variance revealed a significant main effect for Sex ($F(1/18)=4.40, MS_e=.069$). In addition, the Sex × Condition interaction followed the same pattern as that found with the resting ratio, though it was not statistically significant ($F(2/36)=2.29, MS_e=.009$). These data suggest that the differential asymmetric engagement of the hemispheres between the sexes is largely a function of task elicited changes and not shifts in lateralization between resting periods.

affect generation phase is illustrated in the same figure. Females show a non-significant decrease ($t(7)=2.096$) in EEG ratio from prefeedback to affect, indicative of greater relative right hemispheric activation during the latter phase. Conversely, males showed a slight increase in ratio. The difference between males and females in hemispheric shift from prefeedback to affect is significant ($t(18)=2.602$). As suggested by the curves, when shifts in EEG ratio between the feedback phase and affect are themselves compared, neither males nor females show any significant differences in hemispheric asymmetry between these conditions.

To more precisely localize the sex difference effect, the up and down and anger and relaxation components of the prefeedback and affect conditions were then separately examined. It was found that 100% of the females showed greater relative right hemisphere activation during anger compared to prefeedback up while only 42% of the males evidenced this effect; this difference is statistically significant ($\chi^2(1)=4.84$, with Yates' correction for continuity (McNemar, 1969, p. 262)). When prefeedback down and relaxation were compared, the trend was in the same direction; a greater percentage of females showed greater relative right hemispheric activation during self-generated relaxation versus prefeedback down, though this difference was not significant.

Finally, during the affect phase itself, mean EEG ratio for females was found to be significantly less than the same ratio for males ($t(18)=2.371$). Apparently, when females are asked to think about emotional scenes from their past, they show greater relative right hemisphere activation compared with males.

Discussion

These data indicate that when people are simply instructed to regulate their heart rate in the absence of any biofeedback, males and females initially show similar patterns of hemispheric asymmetry. However, when biofeedback is introduced, sex differences emerge, with females shifting to greater relative right hemisphere activation comparable to what they show when specifically instructed to think emotional thoughts. Based on the literature reviewed in the introduction, it can be hypothesized that males and females may both employ covert somatic strategies during initial prefeedback cardiac control. However, when feedback is introduced, the present data indicate that females show a significant increase in relative right hemispheric activation suggestive of a shift to a more affective strategy, while interhemispheric relationships in the male EEG remain unchanged. When the covert affect phase is examined by itself, sex differences in hemispheric asymmetry are observed with females showing greater relative right hemispheric activation than males.

To determine whether this effect simply reflected a difference in perceived intensity of affect, subjects were asked to rate after each trial, the intensity of their emotional experience during that trial on a scale from 1 to 5. Interestingly, there were no significant differences between the sexes on this measure. Although the rated intensity of affect may be similar, the present data do not preclude the possibility that the males and females experienced these emotions using different cognitive modes. It could be hypothesized that males, even when experiencing affect, may do so in the context of a more analytic, propositional framework while females may typically process affect in a more global and gestalt-like manner. In other words, affective self-generation in males may be accompanied by more bilateral involvement than seen in females performing the identical task at a comparable level of self-perceived affective intensity. However, more systematic and sophisticated procedures for assessing both subjective report and affect (e.g. Schwartz, Fair, Greenberg, Freedman, & Klerman, 1974) are needed to evaluate this hypothesis.

Differences in cognitive strategy would be consistent with recent literature on sex differences and cerebral lateralization where a variety of evidence has been accumulated which suggests that some cognitive modes may be more lateralized in females than in males. For example, Davidson et al. (Note 1) have found in three separate studies greater cerebral asymmetry during a variety of self-generation tasks in females than in males. Buffrey and Gray (1972) argue from a variety of data that lateralization of language function occurs earlier and progresses more quickly in the female brain than in the male brain and these differences probably persist into adulthood. Consequently, the non-dominant hemisphere of the female will be freer to subserve non-verbal function. These investigators argue that most forms of spatial skill benefit from a more bilateral cerebral representation which they suggest is characteristic of male brains.

This hypothesis, however, is not universally accepted. Levy (1972) has arrived at virtually the opposite conclusion on the basis of the seemingly similar performance of left-handers and females on spatial tasks. Since both groups perform more poorly on such tasks relative to their opposites (i.e., right-handers and males respectively) (Levy, 1969; Porteus, 1965; Smith, 1967), Levy (1972) reasons that "it might be that female brains are similar to those of left-handers in having less hemispheric specialization than male right-hander's brains [p. 174]."

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There are a number of conceptual and methodological difficulties with the above formulation. As Marshall (1973) has pointed out in a review of the two contrasting hypotheses (Levy vs Buffrey and Gray), the Levy position depends critically upon the truth of its initial assumption, namely, that bilateral representation for linguistic skills will be found in a substantial proportion of the normal left-handed population. On the basis of the available evidence, this assumption is questionable (Marshall, 1973; Milner, Branch, & Rasmussen, 1964; Pratt, Warrington, & Halliday, 1971; Warrington & Pratt, 1973). Moreover, McGlone and W. Davidson (1973) have demonstrated that only those left-handers with right hemisphere dominance (as assessed by a dichotic procedure) were inferior to right-handers on Thurstones' Primary Mental Ability(PMA) Spatial Relations Test (1958). Furthermore, these investigators failed to confirm the intrahemispheric competition hypothesis. No evidence of inferior performance was obtained on the PMA Spatial Relations Test in subjects with both verbal and non-verbal cognitive functions mediated by the same hemisphere.

The present findings suggest that during the self-regulation of heart rate and affective imagery, sex differences in cerebral asymmetry emerge while heart rate changes during these tasks are comparable between the sexes. In addition, these data indicate that although EEG parietal asymmetry may be comparable within each sex between conditions (for example, between the feedback and affect phases), cardiac rate may be readily dissociated from such cortical patterning. The functional independence observed between these particular response systems is consistent with contemporary knowledge of the relative specificity of different cortical regions (e.g. Luria, 1973). For example, on the basis of such neuropsychological facts, one would predict that the posterior parietal regions would be particularly involved with perceptual and cognitive processing while the more anterior motor regions would be more closely linked with somatic processes and heart rate. Support for this hypothesis has recently been obtained in our laboratory in two separate experiments (Neyer, 1974; Schwartz & Bergman, Note 2).

The data from this experiment underscore the perspective emphasized in our previous research of assessing specific patterns of physiological activity in order to discover the mechanisms employed and strategies invoked during different self-regulatory procedures (Schwartz, 1975a, 1975b; Schwartz, Davidson, & Pugash, Note 3). The present findings specifically suggest that during heart rate biofeedback, cerebral asymmetry in females is comparable to what they show during affective imagery while interhemispheric relationships in the male EEG do not significantly change. The pattern of sex differences uncovered in the present study highlight the utility of the perspective employed and suggest that such an approach may be fruitfully adopted in the study of the neural substrates of individual differences during self-regulatory tasks.

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(Manuscript received May 19, 1975; revision received August 25, 1975; accepted for publication September 15, 1975)