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Individual Differences in Ability to Control Heart Rate: Personality, Strategy, Physiological, and Other Variables

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ABSTRACT

Three experiments (total N = 102) are reported which examined the relationship between individual differences in ability to control heart rate (HR) with feedback and differences in self-reported cognitive strategies, personality variables (locus of control, state and trait anxiety), physiological variables (respiration, somatic activity, basal HR and HR variability, and initial ability to control HR without feedback), and several auxiliary variables (e.g., weight, smoking, gender, exercise, and meditation). Two sets of analyses were performed. In the first set, differences in cognitive strategies and physiological concomitants between HR decrease and HR increase were studied revealing disparate patterns of cognitive strategies and physiological concomitants for the two directions of HR control. In the second set, the group of cognitive, strategy, personality, physiological, and auxiliary variables was searched to determine if any variables were related to individual differences in ability to decrease or increase HR. Cognitive strategies, personality, and auxiliary variables were generally unrelated to ability to control HR in either direction. Use of two cognitive strategies was found to be associated with lack of ability to increase HR, and non-smokers were better able to decrease HR. Strong relationships were found for somatic activity and ability to control HR without feedback, both of which successfully predicted differences in ability to decrease and increase HR with feedback. Implications of these findings for past and future studies of voluntary control of HR are discussed.

DESCRIPTORS: Individual differences, Heart rate, Voluntary control, Biofeedback, Cognitive strategy, Locus of control, Anxiety.

In this report, data from three experiments are applied to an examination of individual differences in ability to control heart rate (HR). The increasing interest in the issue of individual differences can be seen in two recent reviews of the literature on voluntary control of HR (McCanne & Sandman, 1976; Williamson & Blanchard, 1979), both of which give it considerable emphasis. From a historical perspective, the original concerns in the human literature mirrored those of the early animal literature, namely, demonstrating the phenomenon of operant conditioning or control of HR and determining its specificity relative to skeletal, respiratory, and non-chronotropic cardiac functions. To this end, the topography of human heart rate control has been explored most often using data averaged across large numbers of individual subjects, thus smoothing over important and potentially interesting individual differences. A second wave of human work addressed methodological and parametric issues which were also well suited to analysis using group data. These issues, comprehensively reviewed by Williamson and Blanchard (1979), included effects of extended training, various feedback parameters, subject motivation, and knowledge of feedback contingencies.

Emergence of the current emphasis on individual differences may reflect a growing dissatisfaction with the amount of new knowledge generated from the large number of studies of voluntary control of HR. Regardless, choice of an individual difference methodology has potential for asking new research questions and generating new kinds of data. The purpose of the present report is to examine the relationship between ability to control HR and a number of potentially relevant variables. Our research question can be stated quite simply: what characteristics differentiate people who differ in ability to control HR? As Williamson and Blanchard's (1979) review indicates, this question has been addressed in terms of several psychological (e.g., locus of control, anxiety) and physiological

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(e.g., resting HR variability) characteristics by different investigators. In the present series of experiments, we were able to compare a number of personality traits, cognitive strategies, patterns of concomitant respiratory and somatic activity, and other variables in a fairly large sample of subjects. Using a method which allowed comparison of the relative importance of these variables, our objective was to provide an overarching perspective on the question of individual differences in ability to control HR. Toward this end, we hoped to identify both promising and unpromising explanations for these differences.

Method

The three experiments to be reported used essentially the same methodology to enable comparison and combination of data across experiments. Experiments I and III have not been reported previously, but physiological data from Experiment II were reported in Levenson (1979).

Subjects

In all, 102 subjects were recruited from introductory psychology classes at Indiana University. In the first experiment, 34 (23 male and 11 female) students were paid $3.00 for participating. In the second experiment, 30 (13 male and 17 female) students were paid $3.00 and fulfilled a course requirement for participating. In the third study, 38 (all male) students fulfilled a course requirement for participating.

Apparatus

Physiological Data. Physiological data were recorded using a Grass Model 7 polygraph and analyzed on-line by a PDP-11 digital computer at a resolution of 1 msec. The electrocardiogram was detected using Beckman surface electrodes placed on opposite sides of the chest, with the computer timing the interval between successive R-waves to yield cardiac interbeat interval (IBI). Respiration intercycle interval (ICI) was determined using a mercury-filled strain gauge stretched across the subject's chest, with the computer timing the interval between successive inspirations. General somatic activity (ACT) was obtained in the second and third experiments by integrating the output of an electromagnetic sensor attached to a platform under the subject's chair. The measure of ACT derived from this system is sensitive to subject movement in all planes and provides a reliable estimate of the total amount of somatic activity engaged in by the subject.

Feedback and Task Information. A LED digital display device was used. The leftmost digit was used to signal the subject as to whether to attempt HR increase, attempt HR decrease, or "rest" (while the pretrial baseline was calculated). The rightmost digit was used to present the HR feedback. A digit was illuminated after each IBI. The digit "5" was equated with the baseline mean IBI plus or minus 30 msec. Successive 60-msec bands were established for digits below and above "5" such that HR increases (shorter IBIs) were associated with higher digits and HR decreases (longer IBIs) were associated with lower digits. Digits "1" to "9" were used, thus covering an IBI range of 540 msec around the baseline mean.

Procedure

In all experiments subjects completed a general information questionnaire, the locus of control inventory (Rotter, 1966), and a trait anxiety inventory (Spielberger, Gorsuch, & Lushene, 1969) upon reporting to the laboratory. Following this, electrodes were attached and the use of the feedback display was explained. Subjects then completed a state anxiety inventory (Spielberger et al., 1969). At this point subjects were instructed to attempt to control their HR while maintaining constant respiration and minimal muscle activity following the appropriate procedure:

Experiment I. The experiment consisted of 12 trials, each trial comprised of a 50 heart beat baseline, a signal to attempt HR decrease or increase on that trial (counterbalanced orders of 6 decrease and 6 increase trials were used), 120 beats of attempted HR control, and a 1-min rest period. During trials 1–4 no feedback was given; during trials 5–12 beat-by-beat feedback of HR was provided. Following trial 12, subjects completed a questionnaire assessing the strategies they used to decrease and increase their HR.

Experiment II. Although this experiment actually consisted of three sessions (Levenson, 1979), only data from the first session were used. The procedure for this session was identical to that of Experiment I.

Experiment III. A two-session design was utilized. In the first session subjects completed the questionnaires used in the other experiments. This session consisted of 6 trials (50 heart beat baseline, 120 beats of attempted HR control) *without* feedback. A counterbalanced ordering of 3 HR decrease and 3 HR increase trials was used. Two days later, subjects returned for a second session consisting of 12 HR control trials *with* feedback (6 HR decrease and 6 HR increase trials in counterbalanced order). Following the last trial, subjects completed a strategy questionnaire as in the other experiments.

Results[1]

Prior to initiating analysis of our data, several decisions were made in order to make the analysis more manageable and the results more easily comprehensible. First, a single index of subjects' ability to control HR was needed. We selected a criterion measure used in other studies from this laboratory (Levenson, 1976, 1979) called Correct IBIs. This is the number of IBIs on a trial which are in the instructed direction and differ from baseline mean IBI by at least 30 msec—corresponding to the amount of change required to change the feedback display by one digit from the baseline digit "5." This measure is directly comparable between experiments since all three used 120-beat HR control trials. It is highly correlated with an alternative measure, the average magnitude of IBI change from

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[1] The .05 rejection level was used unless otherwise stated.

baseline ($r(100) = .87$ for HR decrease trials, $r(100) = -.91$ for HR increase trials in these experiments), but is more reflective of consistent HR control across the entire trial, compared to mean IBI change (which would be more affected by a large magnitude change of short duration). We also decided to combine data from subjects in the three experiments whenever possible to increase the generalizability of our findings. The option of reverting back to individual experiment data was preserved to determine if a given finding obtained using combined data held in the three individual experiments. Finally we decided to perform two separate sets of analyses, one to determine differences between HR decrease and HR increase trials in strategies and physiological concomitants, and a second set of analyses (detailed below) which separately dealt with HR decrease and HR increase trials to search for variables which were related to individual differences in ability to control HR in each direction.

HR Decrease vs HR Increase

Subjects' reports of frequency of use of 17 strategies for controlling HR on HR decrease and increase trials were analyzed using analyses of variance (ANOVAs). These analyses revealed 15 strategies which were reported differentially for decrease and increase trials (Table 1). The pattern of differences confirmed common sense expectations with the largest differences for "make yourself feel excited" (HR increase), "think about physical exercise" (HR increase), "think about something peaceful" (HR decrease), and "make yourself feel relaxed" (HR decrease). Interestingly, subjects reported watching the feedback display more frequently on HR increase trials, providing support from the subject's perspective for the contention that feedback is especially helpful for HR increase (Williamson & Blanchard, 1979). In addition, subjects reported attempting HR decrease to be more pleasurable than HR increase, $F(1/65) = 25.45, p < .001$.

Two possible physiological concomitants of HR change, ICI change from baseline and ACT change from baseline, were also compared between HR decrease and HR increase trials *with feedback* using ANOVAs on data from Experiments II and III (ACT was not measured in Experiment I). These variables differed between the two kinds of trials with faster respiration rate (shorter ICI) on HR increase trials, $F(1/67) = 65.1, p < .001$, and greater ACT on HR increase trials $F(1/67) = 6.38, p = .013$. Finally these variables were compared between HR decrease and HR increase trials *without feedback* revealing the same pattern of faster respiration rate on HR increase trials, $F(1/67) = 50.29, p$

TABLE 1

Heart rate decrease vs increase: Strategy variables

Strategy	Frequency of use (1–5 scale) HR Decrease	HR Increase	N[a]	$F(1/N-1)$
Stare at object in room	2.76**	2.25	100	15.66
Think about past event	2.84	3.43**	67	14.85
Think about physical exercise	1.09	3.20**	100	299.79
Will HR to change	3.57	3.51	67	<1
Think about sexual activity	1.31	2.42**	67	47.21
Make yourself feel relaxed	4.47**	1.70	66	177.71
Think about something peaceful	3.64**	1.25	67	213.87
Make yourself feel angry	1.07	2.66**	67	90.50
Make yourself feel afraid	1.13	2.36**	67	56.30
Make yourself feel sad	1.84*	1.36	67	10.22
Make yourself feel excited	1.15	3.69*	67	272.02
Clear your mind completely	3.33**	1.87	67	65.40
Make yourself feel happy	1.90	2.33**	67	5.90
Think about something violent	1.07	2.73**	67	111.24
Meditate	1.51**	1.03	98	18.61
Repeat phrases to yourself	1.83	1.85	66	<1
Watch feedback display	3.70	3.91**	99	12.05

[a] Strategies with an N of 67 or less were assessed only in Experiments II and III.

*More frequent, $p < .05$.

**More frequent, $p < .001$.

< .001, and greater ACT on HR increase trials, $F(1/65) = 3.87, p = .051$.

Individual Differences in Ability to Control HR

Data Analysis. Previous studies of individual differences have all used univariate statistics essentially to ask the question: Is variable "X" related to individual differences in ability to control HR? To allow comparison with the results from these studies, we initially adopted a univariate correlational strategy for data analysis. The large number of measured variables in the present study were also subjected to multivariate regression analyses (described below) to further our understanding of the manner in which groups of variables were related to individual differences in ability to control HR.

Univariate correlations with the number of correct IBIs on HR decrease trials were determined for personality variables, strategies and concomitant physiological variables during HR decrease, and other measured variables. Then a parallel set of correlations was performed for HR increase data[2]. Significant correlations in these analyses were interpreted as indicating that a measured variable was related to individual differences in ability to control HR. The separate analysis of HR decrease and HR increase data reflects the likelihood that different mechanisms underlie the two directions of HR control (as suggested by Lang, 1975), and our observation that correlations between ability to decrease and increase HR were quite low, $r(100) = .00$, in the present data.

Since some investigators have reported quadratic or "U-shaped" relationships between personality variables and ability to control HR (e.g., trait anxiety in McFarland & Coombs, 1974), we attempted to address this possibility. Subjects were ordered in terms of number of correct IBIs on HR decrease trials with feedback. Then the 18 most successful and least successful HR decreasers were assigned to two groups, with the remaining subjects assigned to a third. In instances where a significant group effect was found, a test for significant quadratic trend was also performed. A parallel set of analyses was performed on HR increase data.

Finally, multivariate regression analyses were performed in which we first removed the variance in ability to decrease HR accounted for by concomitant physiological variables (change in ICI and ACT). Then regression procedures were employed separately for strategy variables and personality variables to determine the extent to which they accounted for additional variance. A parallel set of multivariate regression analyses was performed on HR increase data. These multivariate analyses were limited to data from Experiments II and III since ACT had not been measured in Experiment I.

Prior to presenting the results of these analyses, the entire set of measured variables will be reviewed. The complete list of strategy variables can be found in Table 1; personality variables were locus of control, trait anxiety, and state anxiety. Auxiliary variables assessed in Experiments II and III were percentage overweight calculated from height-weight data (Metropolitan Life Insurance Company, 1959), whether subject smoked, amount of regular exercise, subject's prediction of success at HR control prior to experiment, and subject's rating of importance of success prior to experiment. In addition, gender and regularity of formal meditation were determined in all experiments. Physiological variables were (in Experiments II and III) ICI change on no-feedback and feedback trials, ACT change on no-feedback and feedback trials, basal HR and HR variability, and (in all Experiments) correct IBIs on no-feedback trials.

HR Decrease. The range of individual differences in ability to decrease HR was substantial, extending from an average of 16 to 112 correct IBIs per trial (maximum possible was 120). Differences in ability to decrease HR were not correlated with subjects' report of their use of cognitive strategies (Table 2). Similarly, ability to decrease HR was not correlated with any of the three personality variables or five auxiliary variables (Table 3).

The small nonsignificant correlations of strategy, personality, and auxiliary variables with ability to decrease HR (Tables 2 and 3) were reflected in nonsignificant group effects in the series of ANOVAs performed on the three ability groupings. One additional analysis was computed to determine whether individuals scoring at the extremes of the locus of control inventory differed in ability to decrease HR. In this analysis the 18 most internal (mean score = 5) did not differ from the 18 most external (mean score = 16) scoring subjects, $t(34) = .44$, in ability to decrease HR.

Two categorical variables, gender and smoking, were analyzed in separate ANOVAs. There were no differences between male and female subjects in ability to decrease HR, $F(1/100) = .06$. However, non-smokers (N = 51) were better able to decrease HR than smokers (N = 16), both without feedback (49 vs 38 correct IBIs), $F(1/65) = 5.24, p = .03$, and with feedback (63 vs 48 correct IBIs), $F(1/65) = 8.96, p = .004$.

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[2] These correlations are not comparable to those presented in Levenson (1979) where individual subjects' IBI, ICI and ACT were correlated for both HR increase and HR decrease trials *together*.

TABLE 2

Individual differences related to ability to control heart rate: Strategy variables

Strategy	Correlation with Correct IBIs—HR Decrease (feedback trials)	Correlation with Correct IBIs—HR Increase (feedback trials)
Stare at object in room	.02	−.07
Think about past event	.02	−.03
Think about physical exercise	−.10	.05
Will HR to change	.09	.07
Think about sexual activity	.04	−.13
Make yourself feel relaxed	.04	−.29*
Think about something peaceful	.02	−.30*
Make yourself feel angry	.06	.06
Make yourself feel afraid	−.03	.13
Make yourself feel sad	.13	.01
Make yourself feel excited	−.08	.01
Clear your mind completely	−.02	−.20
Make yourself feel happy	.10	−.10
Think about something violent	−.05	.07
Meditate	.04	−.07
Repeat phrases to yourself	.08	.12
Watch feedback display	.07	−.05

*$p<.05$.
**$p<.001$.

TABLE 3

Individual differences related to ability to control heart rate: Personality, auxiliary and physiological variables

Variables	Correlation with Correct IBIs—HR Decrease (feedback trials)	Correlation with Correct IBIs-HR Increase (feedback trials)
Personality		
Locus of control	.02	−.02
Trait anxiety	−.10	−.07
State anxiety	−.07	.02
Auxiliary		
Percentage overweight	−.01	−.02
Regular exercise	.07	−.16
Prediction of success	.00	−.06
Importance of success	.00	−.07
Regular formal meditation	−.10	.10
Physiological		
ICI change (feedback trials)	−.17	−.12
ACT change (feedback trials)	−.22*	.43**
Correct IBIs (no feedback trials)	.41**	.58**
Baseline IBI (no feedback trials)	.14	−.07
Baseline IBI standard deviation (no feedback trials)	.09	−.08

*$p<.05$.
**$p<.001$.

Among physiological measures, ACT was related to ability to decrease HR on feedback trials, with lower levels of activity on feedback trials associated with greater success at decreasing HR, $r(66) = -.22, p = .036$. Further, the same relationship was found between HR decrease on feedback trials and ACT change on no-feedback trials, $r(64) = -.25, p = .021$. Thus, prior to the introduction of feedback, subjects destined to be successful at HR decrease were already modulating general activity in the manner most conducive to HR decrease. The highest correlation with ability to decrease HR *with* feedback was obtained for ability to decrease HR *without* feedback, $r(100) = .41, p < .001$. In Experiment III, where the most severe test of this relationship occurred (the no-feedback and feedback portions were separated by several days), a significant correlation was still obtained, $r(36) = .53, p < .001$. Finally, there were no relationships between baseline IBI or IBI variability and ability to decrease HR.

Multivariate regression analysis revealed that prediction of ability to decrease HR based on changes in ACT and changes in ICI was not improved by adding either the set of three personality variables, $F(5/62) = 1.71, p = .15$, or the set of 17 strategies, $F(17/46) < 1$. Since hierarchical inclusion of the 17 strategies into the regression equation together used up a large number of degrees of freedom, we computed a second analysis in which strategy variables were selected one at a time in a stepwise manner (after hierarchical inclusion of ACT and ICI). In this analysis, strategy variables still failed to significantly improve on the prediction of ability to decrease HR based on changes in ACT and ICI.

HR Increase. The range of individual differences in ability to increase HR was even greater than the range for HR decrease, extending from an average of 5.5 to 118 correct IBIs per trial. Individual differences in ability to increase HR showed significant *negative* correlations with two strategies, "make yourself feel relaxed" and "think about something peaceful" (Table 2). A comparison of data from the 18 most and 18 least successful HR increasers revealed that the most successful increasers reported lower use of the ". . . relaxed" strategy (means = 1.2 vs 1.9), $t(32) = 2.33$, $p = .027$, and ". . . peaceful" strategy (means = 1.1 vs 1.5), $t(33) = 2.22$, $p = .034$. Examination of the means (which could range from 1 to 5) indicates that neither group reported extensive use of these two strategies, but that the successful group reported almost never using them. Further, use of the ". . . relaxed" strategy was negatively correlated with use of several popular strategies for HR increase including "think about physical exercise," $r(66) = -.23$, $p = .03$, "make yourself feel angry," $r(66) = -.30$, $p = .007$, and "think about something violent," $r(66) = -.39$, $p < .001$.

The ability to increase HR was not significantly correlated with any of the three personality or the five auxiliary variables (Table 3). However, when data from the ANOVAs on the three ability groupings were analyzed, there was a significant group effect for trait anxiety, $F(2/99) = 4.42$, $p = .015$. Trend analysis revealed a significant quadratic trend, $F(1/98) = 6.34$, $p = .013$, with trait anxiety scores of the most successful HR increasers falling above those of moderately successful HR increasers and below those of the least successful HR increasers. Using the eta^2 statistic as an indicator of total variance accounted for and the r^2 statistic as an indicator of variance accounted for by the linear term, the quadratic trend was found to account for 5.9% of the variance in ability to increase HR. The quadratic relationship between trait anxiety and ability to increase HR seems to replicate a finding of McFarland and Coombs (1974) that moderate levels of trait anxiety are associated with greatest success at HR increase. However, the relationship was not very robust. When the analysis was reversed and subjects were divided into the 18 highest and lowest scorers on the trait anxiety scale (with the remaining subjects in a third group), the three groups did not differ in terms of number of correct IBIs on HR increase trials, $F(2/99) < 1$, with a nonsignificant quadratic trend, $F(2/98) < 1$. Thus, we feel comfortable stating only that with the specific tripartite division of subjects in terms of ability to increase HR utilized, there was some evidence of a relationship with trait anxiety. None of the other ANOVAs on ability groupings for personality and auxiliary variables had significant group effects. The set of ANOVAs for strategy variables similarly had no significant group effects other than the ". . . relax" and ". . . peaceful" strategies indicated earlier. In the case of these latter two strategies, the quadratic trend was nonsignificant. The additional analysis of individuals scoring at the extremes on the locus of control inventory revealed no differences in ability to increase HR, $t(34) = .68$.

Among the categorical variables, gender and smoking, no differences in ability to increase HR were found between male and female subjects, $F(1/100) < 1$, or between smokers and non-smokers, $F(1/65) < 1$.

Analysis of physiological measures indicated that ACT was related to ability to increase HR, with greater success at HR increase on feedback trials associated with larger ACT increase on feedback trials, $r(66) = .31$, $p = .005$. Further, the same relationship was found between HR increase on feedback trials and ACT increase on no-feedback trials, $r(66) = .43$, $p < .001$. Thus, as was the case with HR decrease data, subjects destined to be successful at HR increase were altering general activity in the manner most conducive to HR increase prior to the introduction of feedback. Again paralleling results for HR decrease, the highest correlation with ability to increase HR *with* feedback was obtained for ability to increase HR *without* feedback, $r(100) = .58$, $p < .001$. In Experiment III, where the most severe test of this relationship occurred, a significant relationship was still obtained, $r(36) = .58$, $p < .001$. Finally, there were no relationships between baseline IBI or IBI variability and ability to increase HR.

Multivariate analyses revealed that prediction of ability to increase HR based on changes in ACT and changes in ICI was significantly improved by addition of the set of three personality variables, $F(5/62) = 3.54$, $p = .007$. However, using the multiple r^2 statistic as an estimate of variance accounted for, the variance accounted for by ACT and ICI (17.6%) was only improved by 2.3% by adding the three personality variables. Addition of the set of 17 strategy variables also significantly improved the prediction of ability to increase HR based on changes in ACT and in ICI, $F(19/45) = 1.97$, $p = .032$. In this case, the variance accounted for by ACT and ICI (17.6%) was improved by 12.5% by the addition of the ". . . relaxed" and ". . . peaceful" strategies, and an additional 15.2% by the addition of the remaining 15 strategies. However, when we used the more conservative multiple r^2 adjusted for the number of variables in the equation, the variance accounted for by ACT and ICI (15%) was not improved by the addition of the three personality variables. Starting again with the variance accounted for by ACT and ICI and using the conservative r^2, the addition of the ". . . relaxed" strategy improved the prediction by 8.5%, but stepwise addition of the remaining strategies produced small improvements which rapidly asymptoted to 0%.

Discussion

This series of experiments started with the large individual differences in ability to control HR which we have observed in our experiments concerned with specificity of cardiac control. When we set out to investigate the phenomenon of individual differences several years ago, we naively expected to quickly uncover the primary variables which accounted for these differences. Three experiments and many hunches later, we have been able to rule out a number of possibilities, and find support for several others. However, the goal of identifying the essential dimension which underlies individual differences in ability to control HR (if such a thing exists) remains elusively beyond our grasp. At this point in our work, it seems reasonable to sum up what we have learned and discuss some implications our findings may have for past and future work on this question.

Strategies

We have found that subjects do report using very different patterns of cognitive strategies when attempting to decrease and increase HR. The exceedingly high *F* values in Table 1 underscore the striking quality of the strategy data; the variation in strategy reports *between* directions of HR control is much greater than the variation among subjects within a direction. With subjects tending to report using the same strategies, it is not surprising that differences in strategies were not strongly related to individual differences in ability to control HR. In the case of HR decrease, we found no relationship at all. But in the case of HR increase, we found two strategies which were univariately related to *inability* to increase HR (i.e. the ". . . relaxed" and ". . . peaceful" strategies), and which still accounted for significant amounts of variance when the effects of two physiological variables, ACT and ICI, were controlled for. We can only speculate why subjects would attempt to create a relaxed and peaceful cognitive state when attempting to increase their HR; perhaps these subjects associated such a state with increased ability to concentrate on the task or increased sensitivity to bodily changes. Regardless, subjects who utilized these strategies were less able to increase their HR than their counterparts who reported minimal use of these strategies. In addition, the intercorrelations among strategies revealed that subjects who reported using the ". . . relaxed" strategy were less likely to report use of strategies such as "think about physical exercise," "make yourself feel angry," and "think about something violent," all of which have face validity for producing HR increase.

With the possible exception of subjects' use of inappropriate strategies for HR increase, we share Williamson and Blanchard's (1979) conclusion that studying cognitive strategies is not likely to increase our understanding of individual differences in ability to control HR. However, we also agree with these authors that the practice of asking subjects to report their cognitive strategies at the end of HR control experiments may obscure potentially important differences since subjects are "cued" to report using logically consistent strategies by the terms HR 'decrease' and 'increase.'

Personality and Auxiliary Variables

The notion that individual differences in ability to control HR are related to an underlying personality dimension is appealing; and adding a personality measure to a cardiac control experiment is easily accomplished. Nonetheless, the evidence concerning personality variables studied in relationship to ability to control HR (i.e., locus of control, anxiety, impulsivity, autonomic perception) was found by Williamson and Blanchard (1979) to be conflicting at best. Our findings concerning locus of control, state anxiety, and trait anxiety generally argue against the importance of these personality dimensions for understanding differences in ability to control HR. The only relationship we found was a qualified one between trait anxiety and ability to increase HR, with moderate levels of trait anxiety found among the best HR increasers. This quadratic relationship has been reported previously (McFarland & Coombs, 1974; Levenson, Note 1) and is reminiscent of the notion that moderate levels of anxiety are associated with improved performance. We do not feel that this is an overwhelmingly powerful relationship since it only accounted univariately for 6% of the variance in ability to increase HR, and did not hold up when subjects were explicity grouped on the basis of anxiety scores. When changes in ACT and ICI were controlled for, even all the personality measures together failed to improve the prediction of ability to decrease HR, and improved the prediction of ability to increase HR by only 2.3%[3].

We conclude from our data and those of other investigators, that in studying the relationship between personality variables and ability to control HR, it may be more fruitful to examine indirect rather than direct relationships. By this we mean that there is really little theoretical basis for expecting subjects who differ on the major personality

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[3] It should be noted that our multivariate regression analysis was only sensitive to linear trends in the data; thus the quadratic relationship between trait anxiety and ability to increase HR would not be included in this estimate.

constructs to differ in an ability (i.e., the ability to control the heart) which has neither a direct conceptual link to the construct, nor was utilized in the validation of the instrument used to measure the construct[4]. However, a conceptually sound indirect relationship may exist which explains the occasional significant relationships found between personality constructs and ability to control HR. As a hypothetical example, a finding that "impulsive" individuals are better able to increase HR than "repressed" individuals makes little conceptual sense. However, if "impulsive" subjects are found to be more physically active during attempted HR increase (compared to "repressed" subjects) despite instructions to remain still, then a more understandable, indirect mediational linkage between the personality construct and HR control can be made.

Turning to our auxiliary variables, these represented what we thought were reasonable candidates as correlates of ability to control HR. Exercise, meditation, weight, and attitudes concerning successful performance all turned out to be unrelated to HR control. Gender was also found to be unrelated, as has been generally the case in the literature (Levenson, 1976; Williamson & Blanchard, 1979).

We did find smoking to be related to HR control with non-smokers better able to decrease HR. On the basis of our data we are unable to make a firm conclusion regarding this relationship since we had only 16 smokers among the 67 subjects for whom these data were obtained. Further, although the directional effect was observed in both Experiments II and III, it reached statistical significance only when the data were combined. In any event, further study of this relationship seems warranted to determine if it is reliable, and if so, how it is mediated.

Physiological Variables

At this point in our discussion we will be taking up issues of cardiac-respiratory-somatic relationships which we have addressed previously (Levenson, 1976, 1979; Newlin & Levenson, 1978). However, the individual differences analyses performed in the present study revealed new aspects of these relationships. The most important of these concerns differences in the cardiac-respiratory and cardiac-somatic relationships when analyzed in the context of comparisons of HR decrease vs HR increase, as opposed to comparisons based on individual differences in ability to control HR. Previously we had concentrated on comparisons between HR decrease and HR increase, finding a pattern of decreased respiration rate and decreased ACT during voluntary HR decrease and a complementary pattern of increased respiration rate (and depth), and increased ACT during voluntary HR increase. These patterns were maintained in the three present experiments, two of which had not been reported previously. However, when we turned to the analysis of individual differences in ability to control HR, we found that ACT was related to these differences but respiration rate was not. Thus, the respiration variable behaved in much the same manner as the strategy variables, with large differences between HR decrease and HR increase trials, but no differences as a function of success at HR control. We interpret this as indicating that just as virtually all subjects reported using the strategy "make yourself feel excited" during attempted HR increase, virtually all subjects tended to increase their respiration rate. In the case of respiration, as contrasted with strategies, the linkage with HR has a biological function and has been shown to be quite robust in our own work and that of others (e.g., Vandercar, Feldstein, & Solomon, 1977). However, the present data indicate that the *amount* of respiratory change is not necessarily related to the *amount* of cardiac change. This simple distinction enables us to integrate our own consistent findings of cardiac-respiratory parallelism with the demonstration by other investigators that pacing respiration at increasingly faster rates does not necessarily lead to monotonically increasing heart rates (e.g., Engel & Chism, 1967; Stroufe, 1971).

The cardiac-somatic relationship behaved somewhat differently. It paralleled the cardiac-respiratory relationship insofar as decreased ACT accompanied attempts to decrease HR, and increased ACT accompanied attempts to increase HR. However, it differed from the respiratory data in that ACT change *was* related to individual differences in ability to control HR. Further, ACT displayed the *only* bidirectional linear relationship with HR control on feedback trials in the entire set of variables. This finding is even more striking if the relative simplicity of our ACT measure is considered. It is quite possible that even stronger relationships between somatic variables and ability to control HR would have been obtained if more comprehensive measures, such as EMG from selected muscle groups, were utilized.

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[4] There are numerous psychometric issues concerning the assessment of personality traits which are important for psychophysiological research. Results obtained using different instruments purporting to measure the same trait may not always be comparable. In addition, subjects' defensiveness when completing self-report inventories may contribute additional error to the assessment procedure and may have implications for the relationship between personality and psychophysiological variables (e.g. Weinberger, Schwartz, & Davidson, 1979).

Thus, at the end of three experiments and what we feel has been a careful examination of many possibilities, we are left with a single behavior which is associated with successful bidirectional control of HR. The relationship can be stated simply: subjects who most limit movement are most successful at decreasing HR and subjects who most increase movement are most successful at increasing HR. The biological basis of this cardiac-somatic relationship is quite clear (e.g., Obrist, Webb, Sutterer, & Howard, 1970). Further, the efficacy of muscle activity for producing changes in HR has been demonstrated by several investigators (e.g., Belmaker, Proctor, & Feather, 1972; Lynch, Schuri, & D'Anna, 1976). Despite this, few studies in the large human literature in cardiac control have included a measure of somatic activity (McCanne & Sandman, 1976; Williamson & Blanchard, 1979).

The single strongest and most reliable relationship in our entire data set was the relationship between ability to control HR *without* feedback and the ability to control HR *with* feedback. This relationship has been noted earlier in single-session designs (Levenson, Gross, & Doxas, Note 2; Bell & Schwartz, 1975), but we felt it needed verification in a two-session design such as Experiment III. Several implications of this relationship can be made. First, it seems unjustified to assert that subjects "learn" how to control HR for the first time in these experiments. They clearly report to the laboratory with pre-existing abilities to control HR. Further, these differences are largely maintained, although some or all subjects may improve upon their initial abilities through practice or by making use of the feedback. Second, our data indicate consistent relationships between ability to control HR with feedback and two other physiological variables: ACT change on feedback trials and ACT change on no-feedback trials. Integrating these findings, the best HR controllers on feedback trials: 1) are the best HR controllers on no-feedback trials, 2) evidence the most somatic parallelism on no-feedback trials, and 3) evidence the most somatic parallelism on feedback trials. On this basis it seems reasonable to conclude that the best HR controllers make maximal use of the only strategy we have found to be related to successful HR control, and that they use this strategy both on the earlier no-feedback trials and later feedback trials.

Conclusions

The three major positive findings derived from this series of experiments are the relationship between individual differences in ability to control HR and individual differences in the use of parallel somatic activity, the relationship between the initial ability to control HR without feedback and the subsequent ability to control HR with feedback, and differences in strategies and physiological concomitants between HR decrease and increase trials. Of these findings, the first two would seem to have the greatest relevance to work on human control of HR. We will present several conclusions based on these findings and on our negative findings regarding personality and strategy variables:

1) The search for individual differences related to ability to control HR remains an important question. Somatic activity is clearly related but falls short of accounting for all of the variability (especially in terms of differences in ability to decrease HR). More sophisticated and comprehensive measures of somatic activity might account for additional variance and their use would be highly desirable. We feel it is unlikely that the personality variables and cognitive strategies assessed in these and other studies will provide the key to understanding differences in ability to control HR.

2) It is important that studies of voluntary control of HR include measures of somatic variables or adequate somatic restraints. When relationships are found between methodological variables (e.g., extended training, feedback modality, subject motivation) and ability to control HR, the extent to which these relationships are mediated by differences in somatic activity needs to be examined. The same holds true for research concerned with purported relationships between personality (and other) variables and ability to control HR, where observed relationships might well be mediated by somatic factors.

3) Pre-experimental abilities to control heart rate are too strongly related to ability to control HR with feedback to be ignored. It may be useful to experimentally control for these differences in some studies of cardiac control and to directly study them in others. In any event, it is unfortunate that such a robust relationship has not yet been systematically studied.

4) While these experiments were not specifically designed to evaluate any of the current major models of voluntary control of HR (Brener, 1974; Lang, 1975; Schwartz, 1974), our major findings can be used to test some of their predictions. None of the models propose relationships between personality or personality-related variables, thus our failure to find such relationships is not contradictory. Our finding of marked differences between HR decrease trials and HR increase trials in subjects' reports of strategies used, and in patterns of concomitant somatic and respiratory activity, are consistent with Brener's notion that instructions to decrease or increase a physiological function produce global pat-

terms of lower or higher arousal respectively. These findings are less compatible with Lang's suggestion that HR decrease is more illustrative of pure visceral learning than HR increase, insofar as our findings indicate both types of control to be associated with changes in somatic activity. None of the models deal explicitly with the existence of pre-training differences in ability to control HR and their strong relationship to subsequent ability to control HR when provided with feedback. Still, this phenomenon might be incorporated within Brener's model by positing individual differences in strength of association between instructions to alter physiological functions and production of an appropriate psychophysiological state, or within Schwartz' model by viewing ability to produce HR change as a motor skill and positing individual differences in innate and/or acquired levels of this skill.

REFERENCES

Bell, I. R., & Schwartz, G. E. Voluntary control and reactivity of human heart rate. *Psychophysiology*, 1975, *12*, 339–348.

Belmaker, B., Proctor, F., & Feather, B. W. Muscle tension in human operant heart rate conditioning. *Conditional Reflex*, 1972, 7, 97–106.

Brener, J. A general model of voluntary control applied to the phenomena of learned cardiovascular change. In P. A. Obrist, A. H. Black, J. Brener, & L. V. DiCara (Eds), *Cardiovascular psychophysiology: Current issues in response mechanisms, biofeedback, and methodology*. Chicago: Aldine, 1974. Pp. 365–391.

Engel, B. T., & Chism, R. A. Effect of increases and decreases in breathing rate on heart rate and finger pulse volume. *Psychophysiology*, 1967, *4*, 83–89.

Lang, P. J. Acquisition of heart rate control: Method, theory, and clinical implications. In D. C. Fowles (Ed.), *Clinical applications of psychophysiology*. New York: Columbia University Press, 1975. Pp 167–191.

Levenson, R. W. Feedback effects and respiratory involvement in voluntary control of heart rate. *Psychophysiology*, 1976, *13*, 108–114.

Levenson, R. W. Cardiac-respiratory-somatic relationships and feedback effects in a multiple session heart rate control experiment. *Psychophysiology*, 1979, *16*, 367–373.

Lynch, W. C., Schuri, U., & D'Anna, J. Effects of isometric muscle tension on vasomotor activity and heart rate. *Psychophysiology*, 1976, *13*, 222–229.

McCanne, T. R., & Sandman, C. A. Human operant heart rate conditioning: The importance of individual differences. *Psychological Bulletin*, 1976, *83*, 587–601.

McFarland, R. A., & Coombs, R. Anxiety and feedback as factors in operant heart rate control. *Psychophysiology*, 1974, *11*, 53–57.

Metropolitan Life Insurance Company. New weight standards for men and women. *Statistical Bulletin*, 1959, *40*, 1–4.

Newlin, D. B., & Levenson, R. W. Efficacy of pattern feedback for the dissociation of heart rate and respiration rate. *Biological Psychology*, 1978, *1*, 277–285.

Obrist, P. A., Webb, R. A., Sutterer, J. R., & Howard, J. L. The cardiac-somatic relationship: Some reformulations. *Psychophysiology*, 1970, *6*, 569–587.

Rotter, J. B. Generalized expectancies for internal versus external control of reinforcement. *Psychological Monographs*, 1966, *80*, 1–28.

Schwartz, G. E. Toward a theory of voluntary control of response patterns in the cardiovascular system. In P. A. Obrist, A. H. Black, J. Brener, & L. V. DiCara (Eds.), *Cardiovascular psychophysiology: Current issues in response mechanisms, biofeedback and methodology*. Chicago: Aldine, 1974. Pp. 406–440.

Spielberger, C. D., Gorsuch, R. L., & Lushene, R. *The State-Trait Anxiety Inventory*. California: Consulting Psychologists Press, 1969.

Sroufe, L. A. Effects of depth and rate of breathing on heart rate and heart rate variability. *Psychophysiology*, 1971, *8*, 648–655.

Vandercar, D. H., Feldstein, M. A., & Solomon, H. Instrumental conditioning of human heart rate during free and controlled respiration. *Biological Psychology*, 1977, 5, 221–231.

Weinberger, D. A., Schwartz, G. E., & Davidson, R. J. Low-anxious, high-anxious, and repressive coping styles: Psychometric patterns and behavioral and physiological responses to stress. *Journal of Abnormal Psychology*, 1979, *88*, 369–380.

Williamson, D. A., & Blanchard, E. B. Heart rate and blood pressure biofeedback. I. A review of the recent experimental literature. *Biofeedback and Self-Regulation*, 1979, *4*, 1–34.

REFERENCE NOTES

1. Levenson, R. W. *Effects of subjects' anxiety on ability to control heart rate and utilize feedback*. Paper presented at the meeting of the Society for Psychophysiological Research, Toronto, October 1975.
2. Levenson, R. W., Gross, G. H., & Doxas, G. *Effects of biofeedback training on subjects differing in initial ability to control heart rate*. Paper presented at the Biofeedback Research Society, 1975.

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