GENETIC INFLUENCE ON PHASIC CARDIAC RESPONDING IN REACTION TIME AND MENTAL ARITHMETIC TASKS: A STUDY OF ADOLESCENT TWINS

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ABSTRACT

It has been reported that heredity influences heart rate (HR) under resting and task conditions and that relatively more genetic influence occurs in mildly stressful tasks (Vandenberg, Clark and Samuels, 1965). Van der Molen and Orlebeke (1980) have reported that individual phasic cardiac response patterns remain very stable over time and over stimulus conditions. The amount of genetic determination of HR responses and of the shapes of phasic HR profiles was investigated in eleven monozygotic (MZ) and eleven dizygotic (DZ) twin pairs in two experimental conditions. In one condition subjects performed a reaction time (RT) task. In the other a mental arithmetic (MA), task was added to the RT task: Either separate RT, or MA trials, or trials in which both RT and MA was combined were presented. MZ twins showed reliably higher intraclass correlations than DZ twins for pre-warning HR level and for peak to valley HR response in the mixed RT and MA condition, but not in the blocked RT condition. Intraclass correlations based on phasic HR profiles were generally low and hardly different between MZ and DZ twins. The greatest difference was found again in an MA task. Within subject split-half correlations were higher during MA tasks than during RT tasks. The results suggest that during a mental stress task which induces sympathetic excitation more genetic influence is manifested in HR than during a vagally controlled perceptual-motor task.

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INTRODUCTION

The contribution of genetic factors in psychophysiological responses has been studied in electroencephalografic, electrodermal and cardiovascular response systems. Although based on divergent statistical methods and sample sizes, there is evidence that heart rate level under resting conditions is controlled by genetic factors (Lader and Wing, 1966; Shapiro, Nicotero et al., 1968; Mathers, Osborne, and DeGeorge, 1961; Vandenberg, Clark, and Samuels, 1965; Hume, 1973). With respect to selected HR responses the results are somewhat contradictory. Vandenberg et al. (1965) reported differences in intraclass correlations between mono- and dizygotic twins under mildly stressful stimulus situations, but Hume (1973) did not find any evidence for genetic influence on HR response.

There are several reasons to assume that phasic heart rate changes are influenced by heredity factors. Phasic heart rate changes under controlled stimulus and response conditions have in general a characteristic morphology. For instance in two-stimuli tasks (S1-S2) the corresponding phasic cardiac response pattern consists of deceleration after the warning signal (S1) followed by acceleration and deceleration until S2 onset. Any random sample of 10 subjects or more shows the same averaged HR pattern under the same task conditions (e.g. van der Molen and Orlebeke, 1980) while under different S1-S2 conditions differences in the corresponding heart rate responses occur (Somsen, van der Molen, and Orlebeke, 1983). This implies that the morphology of the cardiac response is for a considerable part determined by objective task conditions.

However, in spite of this substantial external task influence individuals many times show unique phasic HR patterns that are very different from each other. Van der Molen and Orlebeke (1980) have found that these differences between individuals can not be exclusively attributed to random variation. In Figure 1 the individual specific responses of four subjects are shown, measured in an RT experiment that was run two times with a time lag of six months. Subjects' cardiac patterns are very different from each other, but do not differ much across time and across a series of stimulus intensity conditions. The figure also shows that these unique patterns only occur under task relevant stimulus conditions. It is evident that the shape of an individual phasic cardiac reaction pattern is not only controlled by the task but also by specific characteristics of the individual.

McCanne and Sandman (1976) concluded from a number of studies concerning individual-specificity in operant HR conditioning that individual-specificity is a significant factor in the cardiac response which has to be taken into consideration. They suggested that individual differences in HR responses may be due to underly-

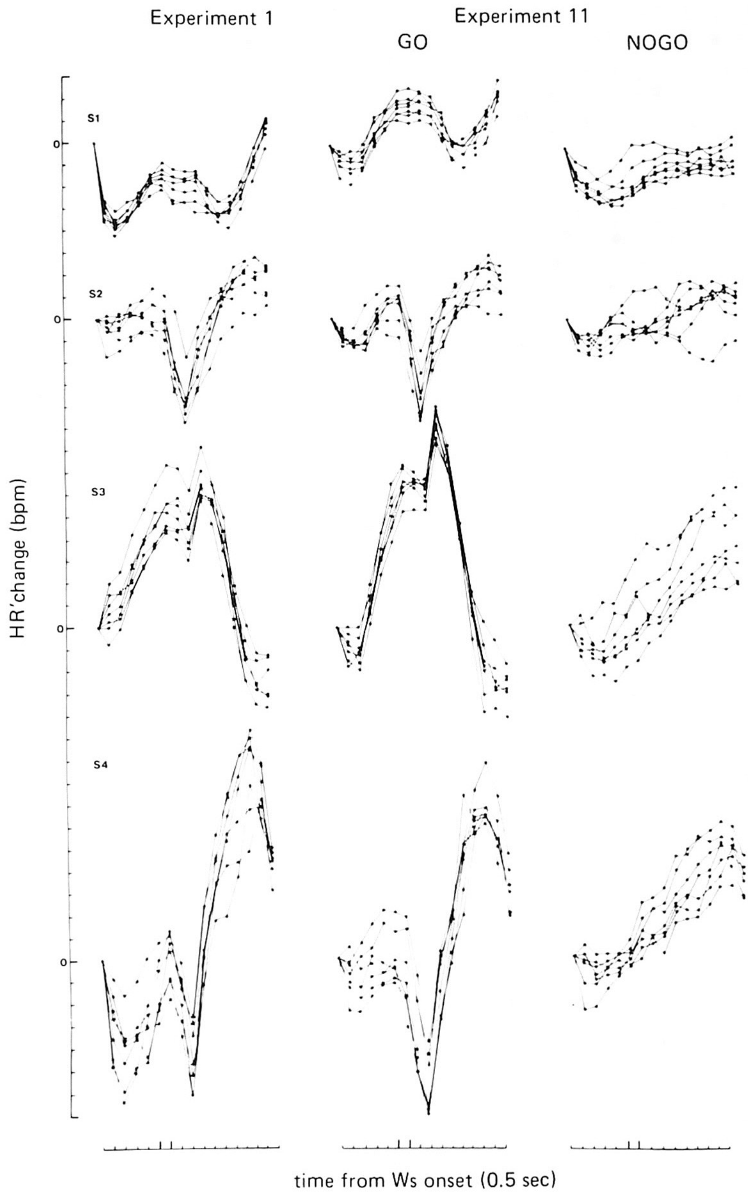

Figure 1. Phasic heart rate change profiles of four subjects in a signalled reaction time task. Each row represents a subject; columns represent identical experiments that were run with a time lag of 6 months. Single lines represent averaged heart rate responses in seven stimulus intensity conditions (ranging from 50 to 110 dB). In the NOGO condition (third column) no reaction time response was required. (From the van der Molen and Orlebeke, 1980 study).

ing differences between individuals in neural organization. Since there exists already considerable individual consistency in the HR responses of newborn infants (Clifton and Graham, 1968), it is likely that part of the individual response pattern results from innate characteristics of the autonomic cardiovascular response system.

This hypothesis can be investigated by comparing the intraclass correlations between monozygotic (MZ) and dizygotic (DZ) twins (cf. Plomin, DeFries, and McLearn, 1980). Intraclass correlations reflect the amount of within pair concordance. Similarity of HR responses of twin pairs can result (grossly) from three main sources: 1. The totally (MZ) or partly (DZ) identical genetic structure of a pair. 2. The equal environments in which the members of a pair (MZ and DZ) grow up. 3. The nature of a particular task in which all (MZ and DZ) twins participate. Assuming that task conditions and common environments have the same influence on both members of a MZ or DZ pair, we may conclude that higher correlations between MZ twins compared to DZ twins must result from genetic factors. The magnitude of twice the difference between MZ and DZ intraclass correlations gives an estimate of the the proportion of variance in the characteristic which is due to genetic factors (Falconer, 1981).

In the current study MZ and DZ pairs participated in S1-S2 tasks under a blocked and a mixed condition. In the blocked condition a series of reaction time trials was presented. These reaction time trials were comparable to the trials used in the van der Molen and Orlebeke study that gave the first report of individual phasic HR response specificity. In the RT trials four interstimulus interval (ISI) lengths (2, 3, 4, and 5 sec) were used. The HR response pattern that is characteristic of a RT task needs some time to develop fully (e.g. Bohlin and Kjellberg, 1979). In a short ISI (2 sec) the typical three phasic cardiac response that occurs in longer ISIs (5 sec or more) is not yet present. Assuming that the cardiac response is influenced at the same time by task and individual factors and that the specific effect of the task on HR in short ISIs is smaller than in longer ISIs, it is likely that the HR response pattern in short ISIs will be relatively more controlled by individual factors, while the influence of stimulus-response specificity increases with increasing ISI length. This implies that we expect that HR patterns in short ISIs will be more under the influence of heredity than in longer ISIs.

The study of Vandenberg et al. (1965) indicates that genetic control of heart rate responses can more clearly be demonstrated in somewhat stressful task situations. To create such a situation subjects also performed a mental arithmetic (MA) task. MA tasks are often applied in stress situations, since they induce increases in sympathetic activity and HR acceleration.

When studying the effects of heredity and other types of individual-specificity on HR responses, the relative contribution of a particular task on HR has to be considered. Results of Somsen et al. (1983) show that the cardiac waveform significantly varies in different task situations. This finding implies that it is necessary to take into account to what extend specific task characteristics influenced the HR results. Therefore the present data have been studied in both ways. The results of the general task analyses are reported by Somsen, van der Molen, Boomsma, and Orlebeke (this volume). The selection of task conditions and response measures to be analyzed in MZ and DZ twins and the interpretation of the results have been based on results of general task analyses.

METHOD

Subjects and Experimental design

Fortyfour paid Ss between the age of 15 and 18 years participated in the experiment. Half of the subjects were monozygotic twin pairs (6 female and 5 male) and the other half were dizygotic twins pairs (6 female and 5 male). The experiment comprised two conditions: A blocked condition consisting of a series of signalled RT trials with different warning intervals and a mixed condition which contained three types of trials: single RT trials, single mental arithmetic (MA) trials, and trials in which MA and RT was combined. Thus, in the mixed condition RT trials were randomly interspaced between MA trials and trials that combined the RT and MA task, while the blocked condition consisted of RT trials only. All subjects had normal heart functions. They were paid a fixed sum for their participation and a bonus of 5c for each correct addition. A detailed description of the experimental design and procedure is presented by Somsen et al. (this volume).

Statistical analyses

Two types of statistical analyses were performed: analyses that are comparable to previous results and analyses that handle the specific issue of likeness of HR response morphologies. To be able to compare the present data with other results, intraclass correlations were calculated for HR level and peak to valley HR response i.e., the difference between maximum acceleration and deceleration. The intraclass correlation is given by

$$t = \frac{MSb-MSw}{MSb+MSw}$$

the between-pair mean square (MSb) minus the within pair mean square (MSw) divided by the sum of the between- and within pair mean squares. The intraclass correlations were calculated separately for MZ and DZ twin groups for mean HR level before the warning signal and maximal HR acceleration minus maximal HR deceleration (peak to valley HR) in the interstimulus interval of the blocked RT trials and the mixed MA trials. The significance of the intraclass correlations is given by the F-values from the corresponding ANOVAs.

The cardiac response patterns were analyzed in two ways. Wilson (1968, 1978) presented a formal method for the analysis of twin data that was based on the two factor mixed design ANOVA model for repeated measures that has been described by Winer (1962, p 302 ff) with one random group factor and one fixed factor. In the random group factor each twin pair constitutes a separate group of subjects. The fixed factor consists of the repeated measures: successive time points in a trial. From the ANOVAs intraclass correlations of HR profiles are determined from the pair*time point interactions:

$$t = \frac{\text{MS pair*time point} - \text{MS error within pair*time point}}{\text{MS pair*time point} + \text{MS error within pair*time point}}$$

These intraclass correlations estimate the amount of similarity of the HR curves in each (MZ and DZ) twin group. To test the reliabilities of the HR data split-half within subject correlations were calculated for the 44 subjects for HR level, peak to valley HR, and the phasic HR profiles.

A second analysis was based on the squared deviation measure (D) (e.g. Fischbein and Nordqvist, 1978). D defines the differences between the HR patterns of a twin pair in one score.

$$D = \sum_{i=1}^{k} \left([(Y_{Ai} - \bar{Y}_A) - (Y_{Bi} - \bar{Y}_B)]^2 / k \right)$$

Y_{Ai} =time point i of twin A, $\bar{Y}_A$ =mean of time points of twin A

Y_{Bi} =time point i of twin B, $\bar{Y}_B$ =mean of time points of twin B

k = number of time points

Significance of differences between D scores can be tested by simple t-tests. According to Fischbein and Nordqvist (1978) the D measure and the ANOVA method are equivalent for the analysis of profile data; the former at the individual pair level and the latter for the sample as a whole.

RESULTS

Selected response measures

Table 1 presents a summary of the intraclass correlations, p values of the difference between the Fisher z transformed correlations, mean responses, and the split-half correlations that were found for HR pre-warning level and peak to valley HR in the interstimulus intervals of the blocked and mixed conditions.

The results show greater intraclass correlations in MZ twins compared to DZ twins for pre-warning HR level in both the blocked and mixed conditions and also for the peak to valley HR response in ISI 2 of the blocked condition. Correlations were only significantly different for pre-warning HR in the blocked condition. The task conditions in which mental arithmetic was required consistently showed higher intraclass correlations for MZ twins compared to DZ twins. This difference was significant for the MA+RT (ISI 5) condition and marginally significant for the MA+RT (ISI 3) and MA conditions.

This lack of significance for the difference between some MZ and DZ correlations is partly due to the small sample size. The power (i.e. the probability of obtaining a significant result) with this sample size is only 50% if the two groups differ in the degree of relationship of $z(MZ) - z(DZ) = .80$ and $\alpha = .05$ (where z is the Fisher z transformation of r): This implies r values for MZ and DZ pairs of .76, .20 , or .80, .30, or .84, .40, or .87, .50. (Cohen, 1977).

It is apparent that a relationship exists between the within subject (split-half) correlations and the significance of the within pair intraclass correlations. For HR level and HR responses in the MA tasks relatively high intraclass correlations and relatively high split-half correlations were present while in the blocked condition low intraclass and low split-half correlations occurred. In MZ twins intraclass correlations gradually decreased with increase in ISI length.

Profile analyses

For both MZ and DZ twin groups and for each condition intraclass correlations were determined based on time points in the interstimulus interval as described in the methods section. Table 2 (panel A) shows low intraclass correlations for both twin groups in the blocked RT trials. Also, correlations did not vary consistently with ISI length.

Table 1. Intraclass correlations, p values of difference between Fisher z transformed correlations, mean scores and within subject correlations (reliabilities) for pre-stimulus heart rate and peak to valley HR in the interstimulus intervals of the blocked condition (RT task with ISIs of 2, 3, 4, and 5 sec) and the mixed condition (two mental arithmetic tasks combined with reaction time and a single MA task).

	INTRACLASS CORRELATIONS Monozygotic Twins 1)	Dizygotic Twins 1)	FISHER z(MZ)-z(DZ) p-value	MEAN MZ (bpm)	DZ (bpm)	RELIABILITY 2)
BLOCKED CONDITION						
Pre-warning HR	.76*	.02	.03	72.4	71.1	.99
Peak to valley HR						
ISI 2 sec	.58*	.22	ns	3.3	3.7	.58
ISI 3 sec	.32	.30	ns	4.6	3.8	.34
ISI 4 sec	.20	.27	ns	5.4	4.9	.60
ISI 5 sec	.14	.14	ns	6.8	6.5	.60
MIXED CONDITION						
Pre-warning HR	.54*	.37	ns	74.2	74.7	.99
Peak to valley HR						
MA+RT (ISI 3)	.80*	.37	.08	8.5	10.3	.77
MA+RT (ISI 5)	.79*	.19	.04	9.3	10.3	.85
MA	.59*	-.01	.08	7.5	8.5	.67

* $p < .05$
ns non-significant
1) 11 pairs
2) 44 subjects

The MA condition showed only once an intraclass correlation which was (non-significantly) greater for MZ twins. Inspection of the split-half correlations also shows low reliabilities for the blocked condition. In the MA tasks within pair correlation was highest in the most reliable HR response condition.

The difference within pairs in shape of HR response profile was also expressed in a D (difference) score (Table 2 panel B).

Table 2. Intraclass correlations on HR profiles (pair*time point interaction) in the interstimulus intervals of the blocked condition (RT task with ISIs of 2, 3, 4, and 5 sec) and mixed condition (two MA tasks combined with RT and a single MA task) (panel A). Minimal squares differences (D) between the HR profiles of a twin pair in the interstimulus intervals of the blocked and mixed condition averaged over monozygotic and dizygotic twins (panel B).

	panel A			panel B	
	INTRACLASS CORRELATIONS		RELIA-	DIFFERENCE SCORES	
	Monozygotic Twins 1)	Dizygotic Twins 1)	BILITY 2)	MZ Twins 1)	DZ Twins 1)
BLOCKED CONDITION					
Phasic HR profile					
ISI 2 sec	-.07	.28	.40	1.61	1.68
ISI 3 sec	.11	.10	.26	2.05	1.84
ISI 4 sec	.13	.00	.34	2.16	2.08
ISI 5 sec	.12	.08	.53	2.24	2.31
MIXED CONDITION					
Phasic HR profile					
MA+RT (ISI 3)	.31	.32	.59	2.80	2.93
MA+RT (ISI 5)	.64*	.21	.69	2.25	2.98
MA	-.14	-.14	.36	2.79	2.82

* p < .05
1) 11 pairs
2) 44 subjects

Although mean D tended to be somewhat smaller in MZ than in DZ twins, t-tests did not show a significant difference in any of the experimental conditions. D scores of both MZ and DZ twins increased as ISI length increased in the blocked condition. This implies that their patterns tended to become less alike when ISI lengthened. This effect was analyzed by an ANOVA with MZ/DZ groups and the four ISI lengths as factors. Squared differences significantly increased with ISI length ($F(3/69) = 2.81$) and no interaction with twin groups was found.

DISCUSSION

The present results show that the nature of the task determines the amount of genetic influence on pre-warning level and on peak to valley HR which replicates both positive and negative findings of previous studies. This is particularly true, when the relatively small power of the present (and previous) statistical tests is taken into account.

The intraclass correlation for pre-warning level in the blocked condition is high in MZ twins and almost zero in DZ twins. This result is untypical (unless we would assume the presence of non-additive genetic variance): DZ twins are also expected to show some correlation, because they share on the average 50% of their genetic information. This predicted pattern of correlations was observed in the mixed condition: some correlation between DZ twins and a much higher correlation between MZ twins.

In the blocked condition the RT trials with an ISI of 3, 4, and 5 sec do not differ between MZ and DZ twins. Only ISI 2 trials show a greater (but non-significant) correlation in MZ compared to DZ twins. This result is in accordance with the absence of genetic control in perceptual tasks, reported by Hume (1973). On the other hand strong indications of genetic influence on peak to valley HR are present in the mental arithmetic tasks. Vandenberg et al. (1965) reported similar results: significant differences between MZ and DZ twins in mildly stressful task situations and no difference in non-stressful situations.

However, the close relationship between intraclass correlations and split-half correlations have to be considered. It is possible that HR activity is to a greater degree controlled by genetic factors in relatively more stressful task situations, but it is also possible that the cardiac response is solely more stable and thus more reliably measured in mental stress tasks. According to this latter alternative HR may be equally under genetic control in very different task situations, but the effect is only demonstrated in highly stable HR reaction patterns. Both alternatives--that are not mutually exclusive but may be interactive--will be discussed in more detail.

With the exception of one study on MZ twins of Block (1967) none of the previous reports on genetic control of cardiac activity have considered the reliability of their data. Block studied MZ twins, who participated in a conditioning procedure with electric shock feedback. Pre- and post-stimulus HR averaged over 5 beats was analyzed. Split-half correlations of about .90 and relatively high intraclass correlations were reported. Thus, high reliabilities were present in a stressful task using a tonic cardiac response measure. Lacey and Lacey (1962) have reported higher (four year test-retest) reliabilities for HR in more stressful tasks and lower reliabilities in less stressful tasks. The present results also show higher reliabilities in more stressful MA tasks than in less stressful RT tasks. Therefore it is conceivable that genetic influences have been present in the HR responses of the RT trials that could not be demonstrated due to the low split half reliabilities of the data. The contradictory results of studies that used relatively more stressful tasks (reporting more often a genetic influence) and studies that used non-stressful tasks, actually, may have been mediated by underlying differences in reliability.

However, the conclusion that the HR response may be more under genetic control in MA tasks than in signalled RT tasks with fixed intertrial intervals is also possible. As has been discussed in relation to the general task results (Somsen et al., this volume), the autonomic nervous system that controls variations in cardiac frequency may function differentially under mental arithmetic and perceptual-motor conditions. HR changes in perceptual-motor tasks are predominantly controlled by changes in parasympathetic autonomic activity (Obrist, Wood, and Perez-Reyes, 1965), while during MA tasks significant increases in sympathetic activity have been reported (Ulrych, 1969). It is likely, that temporal external task requirements have a substantial effect on vagal activity, while sympathetic excitation is controlled by ideosyncratic and relatively stable stress responses of the individual. Evidence for genetic control of sympathetic activity i.e., activity of the DBH enzyme which acts as a catalyst during the transformation of dopamine into noradrenaline, was reported by Propping and Kopun (1973). Thus, different patterns of autonomic cardiac control may explain the differences in genetic influence between the blocked and mixed conditions. Task-related predominantly vagally induced HR changes in the blocked RT trials may have been controlled to a lesser extend by genetic factors than relatively more individually determined sympathetic responses in the MA trials of the mixed condition. Moreover, phasic HR profiles were recorded on half second-by-half second basis. As Karemaker (this volume) indicated, heart rate is only affected by sympathetic changes after a delay of 2 to 3 seconds, while vagal changes affect heart rate almost immediately. This implies, that the characteristic shape of an individual HR profile is largely determined by changes in vagal excitation and inhibition, which could explain the failure to demonstrate genetic control of these profiles.

It has been assumed that the HR response may become more under control of task parameters and less under control of individual factors as ISI length increases. The general task results (Somsen et al., this volume) have shown that the three-phasic HR pattern that is characteristic for a signalled RT task is present in the ISI 4, and 5 trials, but is absent in the ISI 2 trials. An interstimulus interval of 2 sec appears to be too short to allow much task-related HR changes. In this situation individual factors, more specifically genetic factors, may be more manifest in the cardiac response. This assumption is in accordance with the data: peak to valley HR correlations are different between MZ and DZ twins in ISI 2 RT trials and do not differ in trials with longer ISIs. Intraclass correlations based on HR profiles did not show this relationship, but the squared difference scores increased with ISI length for both MZ and DZ twins which could indicate that the influence of the task became more manifest in longer ISIs.

The current results strongly suggest that heredity influences heart rate responses. However, the amount of genetic influence may not be fixed. The reliability of the cardiac response, its task relatedness, the stressfulness of the situation, and mediation of different patterns of autonomic control each may influence the amount of genetic control of heart rate. An extensive and carefully designed study is needed in which a considerable sample of MZ and DZ twins (and preferably also their parents and siblings) participate. For the reliable registration of the cardiac responses in the perceptual-motor and cognitive tasks well-trained subjects and a great number of trials are needed. In addition, the pattern of sympathetic and parasympathetic cardiac innervations in the different tasks has to be studied. These methodological conditions allow the application of advanced statistical techniques to untangle the relative contributions of heredity, environment, tasks, autonomic stress responses, and their interactions on cardiac responding.

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