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Original Articles

Relationships Between Central and Autonomic Measures of Arousal at Age 15 Years and Criminality at Age 24 Years

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• Previous studies have indicated that criminality is in part genetically determined, but it is not clear how this predisposition manifests itself at a biological level. This prospective study tests the hypothesis that a psychophysiological predisposition to criminality partly manifests itself through autonomic and central nervous system underarousal. Psychophysiological measures, taken at the age of 15 years, were related to criminality status that was assessed at the age of 24 years. Criminals had a significantly lower resting heart rate, skin conductance activity, and more slow-frequency electroencephalographic activity than noncriminals. Differences were not mediated by social, demographic, and academic factors. These results constitute the first clear evidence that implicates underarousal in all three response systems (electrodermal, cardiovascular, and cortical) in the development of criminality. Although arousal variables correctly classified 74.7% of all subjects, psychophysiological factors alone cannot fully account for criminal behavior and do not negate the potential role of social variables in predicting criminal behavior.

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There is increasing evidence that criminal behavior is in part genetically determined. While early twin studies have been criticized on methodological grounds, several large-scale adoption studies have provided strong support for this position. Bohman and colleagues,[1-3] in three analyses of 862 Swedish adoptees, observed increased rates of criminality in the biological parents of petty criminals. Mednick and associates[4] similarly observed evidence of genetic factors in an analysis of 14 427 Danish adoptees. Several other adoption studies have provided strong support for this main finding.[5-8]

The question of how this genetic predisposition may manifest itself in criminal behavior has, in contrast, received little attention. One reasonable possibility is that measures of central nervous system (CNS) and autonomic nervous system (ANS) activity that themselves have a genetic basis[9-11] may partly represent the genetic predisposition to criminality. Indeed, it is increasingly argued that psychophysiological variables are related to criminal behavior.[12-14] In particular, it has been suggested that ANS and CNS arousal is lower in criminals.[13] Research findings have, however, been conflicting.[12,14,15] Although some studies have reported significantly reduced arousal in one response system in criminals, many others have failed to support these findings.[12]

A major difficulty with drawing conclusions from studies that find reduced arousal in criminals is that they report results from only one of the three most commonly measured psychophysiological response systems (electrodermal, cardiovascular, and cortical). No study, to date, has been able to demonstrate evidence for underarousal (lower arousal in criminals relative to noncriminals) in all three of these physiological systems; indeed, to our knowledge, no study comparing criminals with noncriminals has found significant differences in more than one of these response systems. Evidence for reduced arousal in all three systems would constitute powerful evidence for the view that underarousal is implicated in criminal behavior.

Almost all previous research has used institutionalized samples of criminals, and nonprisoner controls have been rarely assessed.[12] Previous conflicting results may therefore be due to the use of inadequate control groups and the effects of institutional crowding and stress on psychophysiological responses.[16,17] Prospective psychophysiological studies on unselected populations can overcome these problems. Only four prospective studies have been carried out, and none have recorded from more than one psychophysiological response system.[18-21] However, each of these studies provides individual evidence that implicates reduced arousal in the development of criminality in the cardiovascular,[18] electrodermal,[19] and cortical[20,21] response systems.

Most theories in this area of research have attempted to explain one specific subgroup of criminals (psychopaths) rather than criminality per se. For example, Quay[22] has argued

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that underarousal may account for pathological stimulation-seeking in the psychopathic criminal, while Lykken[23] has suggested that psychopathic criminals are less aroused than nonpsychopaths under stressful conditions. Eysenck,[13] however, has developed a general theory of criminal and antisocial behavior that argues that criminal behavior is partly determined by a poorly developed conscience and a reduced sensitivity to punishments relative to noncriminals. It is argued that reductions in both ANS and CNS arousal represent the basic psychophysiological underpinnings to this deficit.[13]

Raine and Venables[24] previously demonstrated that measures of antisocial behavior in 15-year-old males were related to reduced cardiovascular arousal as measured by resting heart rate levels (HRLs), and further research has indicated this finding to be robust.[18,25] However, while antisocial adolescents were also found to show reduced electrodermal activity to orienting stimuli,[26] no significant group differences were observed for resting skin conductance levels (SCLs) and electroencephalographic (EEG) activity.[27] As such, the hypothesis of underarousal in antisocial adolescents received only partial support.

This study tests the hypothesis that underarousal of both the CNS and ANS are related to criminal behavior by relating psychophysiological measures (electrodermal, cardiovascular, and cortical) recorded at the age of 15 years to criminality at the age of 24 years. If underarousal partly determines criminality, psychophysiological measures taken in adolescence should be capable of predicting criminality status in adulthood.

METHODS

Subjects

Subjects consisted of 101 male schoolchildren who were 15 years old (range, 14 through 16 years) when they were originally tested in 1978 and 1979. All but 1 of the 101 subjects were white. Subjects were selected from three schools in England. School 1 was a "secondary modern" school (that took academically poorer children), and school 2 was a "grammar" school (that took academically better children), while school 3 was a "comprehensive" (unselected) school. Subjects were sampled from these three schools (31%, 14%, and 55%, respectively) in proportions that would yield a representative cross section of children in terms of academic and social background.[27] The catchment area for school 1 was largely lower-class neighborhoods; for school 2, it comprised residential and rural neighborhoods; and for school 3, it comprised mixed neighborhoods. Written informed consent was obtained from parents and subjects.

Criminal Status

Subjects underwent psychophysiological testing during the period 1978 and 1979. In December 1988, searches were made for all subjects at the computerized central Criminal Records Office in London, England. This is a national system that registers offenses committed anywhere within Great Britain. Only subjects who were found guilty and sentenced at court were classified as "criminal." By using these criteria, 17 of the 101 subjects were found to possess a criminal record (the sole nonwhite subject in the sample received a classification of noncriminal). This rate of 17% agrees fairly closely with the rate of 16.2% from the ages of 15 through 24 years reported by Farrington[28] for an English cohort similar to the present study population. Offenses ranged in severity from theft to wounding (injury), with the most common offenses being burglary and theft. Five of the 17 subjects had been imprisoned at some point in time following psychophysiological testing; others received penalties of probation orders, community service, and fines. Crimes recorded in the Criminal Records Office are synonymous with "serious" offending,[28] and they do not include trivial offenses, such as traffic offenses. Consequently, the definition of criminality status is relatively strict. The 17 offenders had committed a mean of 7.3 offenses (median, 1.0; mode, 1.0). One of the 17 offenders had a registration for theft that occurred at the age of 14 years and that preceded psychophysiological testing by 3 months. In all other cases, registration for criminal offenses occurred in a period following psychophysiological testing.

Social and Academic Characteristics

Criminals were compared with noncriminals on age and a number of social variables of relevance to delinquency and crime. The total sample was relatively homogeneous with respect to age (all were between 14 and 16 years), with only a small difference of 0.2 years between the groups (criminals, 14.8 years; noncriminals, 14.6 years). Due to the small variance in age, however, this difference was marginally significant ($t = -1.96$, $P<.06$). While criminals were from slightly lower socioeconomic backgrounds, as assessed on the Office of Population Censuses and Survey's classification of occupations (criminals = 3.5, noncriminals = 2.9), this difference was nonsignificant ($P<.16$). A residential classification was made on the basis of whether subjects were residents in areas of high crime (housing estates) or of low crime (residential areas and rural areas). As expected, 41% of the criminal group resided in areas of high crime as compared with 24% of noncriminals ($P<.07$). There was a significant association between criminality status and school status ($\tau = -.16$, $P<.04$), indicating that criminals were of poorer academic ability (tending to come from secondary modern schools that catered for children of lower academic ability) than noncriminals.

Psychophysiological Recording

Skin Conductance.—Bilateral skin conductance was measured from bipolar leads on the medial phalanges of the second and third fingers by using silver–silver chloride electrodes (Beckman) and 0.5% potassium chloride in 2% agar-agar as the electrolyte. The effective skin area in contact with the electrolyte was delineated by a double-sided adhesive mask with a hole that measured 0.45 cm in diameter. Electrodes were attached to the fingers by using adhesive tape (Sleek). Both channels were recorded by using a polygraph (Grass Model 7D). A constant-voltage system[29] was used in configuration with preamplifiers (Grass Model 7P1) and driver amplifiers (Grass Model 7DA). The gain was set at 0.1 mV/cm, and the high-frequency cutoffs were set at 75 Hz. Amplification allowed identification of all skin conductance responses (SCRs) greater than 0.05 microsiemens (equivalent to a pen deflection of 0.5 mm).

The SCLs were noted at the start and the end of the 2-minute rest period. The beginning and the end of the rest period were selected for analysis to provide information on whether arousal fluctuated throughout the 2-minute period. The number of nonspecific SCRs (NS-SCRs) that occurred within the 2-minute rest period was also recorded. The NS-SCRs are spontaneously occurring SCRs that arise in the absence of a stimulus and have been traditionally viewed as an index of electrodermal arousal.

Heart Rate.—The heart rate was recorded by using silver–silver chloride electrodes (Beckman) and a standard lead 1 electrode configuration, with an electrode jelly (Cambridge) that served as an electrolyte medium. The electrolyte was rubbed onto recording sites before electrode application until the skin attained a slight erythema, while electrodes were attached by using adhesive tape (Sleek). The heart rate was recorded on an eight-channel polygraph (Grass Model 7D) by using an electrocardiographic preamplifier (Grass Model 7P4) and a direct-current driver amplifier (Grass Model 7DA). The gain was set at 0.5 mV/cm, with a high-frequency cutoff at 75 Hz and a time constant set at 0.03 second (3-Hz cutoff). The HRL was hand-scored from the polygraph chart, with the sample intervals consisting of the first and last 30 seconds of the 2-minute rest period.

EEGs.—The resting EEG was recorded between the vertex and linked mastoids by using silver–silver chloride cup electrodes (Beckman) with the forehead as ground. The electro-oculogram was recorded from above and below the supraorbital and infraorbital ridges of the left eye with silver–silver chloride miniature electrodes (Beckman) that were attached with adhesive collars. Electrode resistances were, in all cases, below 10 kΩ and, in the large majority of cases, below 5 kΩ. The EEG and electro-oculogram were recorded by using alternating current preamplifiers (Grass Model 7P5) and direct current driver amplifiers (Grass Model 7DA). High- and low-frequency cutoffs were set at 75 and 0.3 Hz, respectively. The EEG was screened for electro-oculographic, muscle, pulse, skin potential, movement, and 50-Hz noise artifacts before analysis. The EEG was digitized at 100 Hz and sampled in 2.56-second epochs. Power spectral density curves were averaged over artifact-free epochs during the 2-minute rest period to yield spectral values for a 0- to 30-Hz frequency range. Averaged spectra were collapsed over 0.39-Hz bands into six frequen-

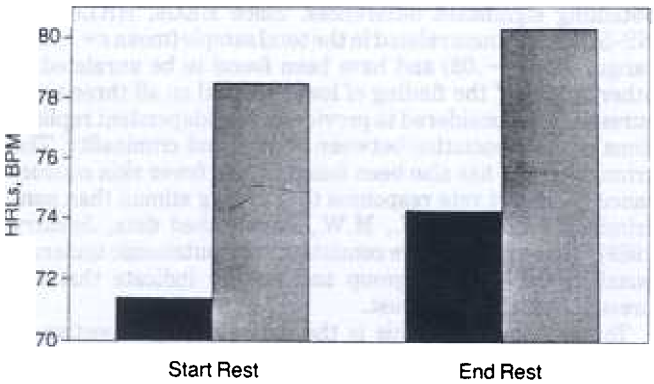

Fig 1.—Heart rate levels (HRLs) in criminals-to-be (closed bars) and noncriminals (shaded bars) at the start and the end of the 2-minute rest period. BPM indicates beats per minute.

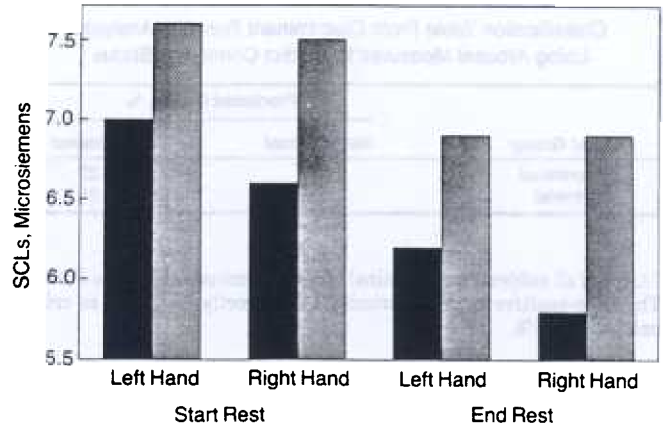

Fig 3.—Skin conductance levels (SCLs) for criminals-to-be (closed bars) and noncriminals (shaded bars) recorded on left and right hands at the start and the end of the rest period.

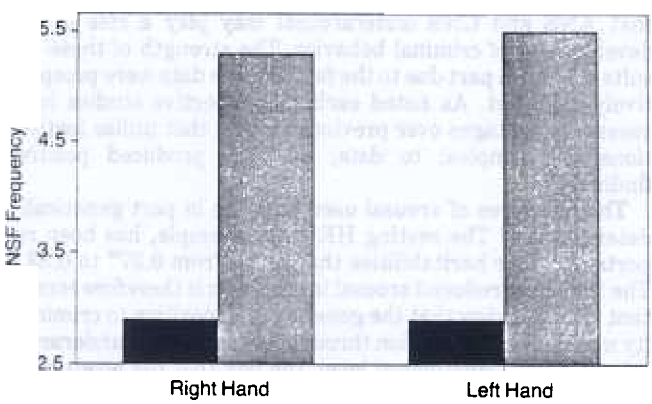

Fig 2.—Nonspecific skin conductance fluctuation (NSF) frequency recorded during the 2-minute rest period on right and left hands in criminals-to-be (closed bars) and noncriminals (shaded bars).

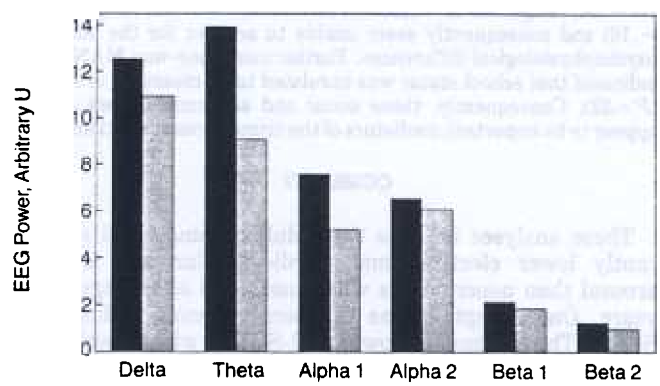

Fig 4.—Electroencephalographic (EEG) power (in arbitrary units) across six frequency bands in criminals-to-be (closed bars) and noncriminals (shaded bars) during the rest period.

cy bands: delta (1.56 to 3.51 Hz), theta (3.52 to 7.42 Hz), alpha 1 (7.43 to 9.37 Hz), alpha 2 (9.38 to 12.49 Hz), beta 1 (12.50 to 17.57 Hz), and beta 2 (17.58 to 24.99 Hz).

Procedure

Individuals were tested in a light- and sound-attenuated laboratory room that was held at a temperature of approximately 21°C. Subjects were made conversant with the equipment, electrode application, and general nature of the experiment. Following electrode application, the subject was seated, asked to get into as comfortable and relaxed a position as possible, and to keep his eyes open throughout the experiment. He was then told that a 2-minute rest period would follow, after which he would hear a series of intermittent tones. Headphones were then placed on the subjects, and the series of tones were initiated. The rest period was followed by an orienting paradigm, classical conditioning, augmenting-reducing, and contingent negative variation, the results of which have been reported elsewhere (A.R., P.H.V., M.W., unpublished data, January 1989).[30] It is likely that the rest period constituted an intermediate level of stress to the subject, but since no independent measure of stress level was recorded, definitive statements cannot be made in this regard.

RESULTS

HRLs

The HRLs at the start and the end of the rest period for criminals-to-be (n = 17) and noncriminals (n = 84) are displayed in Fig 1. A group × period repeated-measures multivariate analysis of variance (MANOVA) revealed a significant main effect for group ($F[1, 99] = 4.9$, $P<.03$), indicating significantly lower HRLs in the criminal group. The crime × period interaction was nonsignificant ($P>.53$).

NS-SCRs

The frequency of skin conductance NS-SCRs for left and right hands throughout the rest period is shown in Fig 2. Due to unequal variances between groups, data were analyzed with the use of t tests by utilizing separate variance estimates. Criminals had a lower number of skin conductance NS-SCRs on both left ($t = 2.3$, $P<.03$) and right ($t = 2.3$, $P<.03$) hands relative to noncriminals.

SCLs

Bilateral SCLs for the two groups are displayed in Fig 3. Although criminals had lower SCLs on both hands for both periods, a three-way repeated-measures MANOVA (group × period × hand) did not confirm this main effect for group to be reliable ($F = 2.1$, $P<.16$).

EEG Power

For EEG power, a group × frequency band repeated-measures MANOVA revealed a significant group × frequency band interaction ($F[5, 490] = 3.1$, $P<.009$). An inspection of Fig 4 indicates that group differences tended to be greater in the low-frequency bands, hence indicating relative cortical underarousal in criminals. Univariate F tests indicated that criminals had significantly more power in the theta frequency band than noncriminals ($P<.001$), with trends occurring also for the delta ($P<.09$) and alpha 1 ($P<.09$) frequencies.

To provide an overall test of the hypothesis that criminals are characterized by underarousal, all arousal measures were entered into a single MANOVA. The main effect for group was significant ($F[14, 74] = 2.2$, $P<.02$), as was the averaged F test ($F = 4.5$, $P<.0005$), indicating that criminals had lower levels of arousal across all measures relative to noncriminals.

By using four variables as predictors (HRL, NS-SCR, SCL, and theta power), a discriminant function analysis correctly classified

Classification Table From Discriminant Function Analysis Using Arousal Measures to Predict Criminality Status		
	Predicted Group, %	
Actual Group	Noncriminal	Criminal
Noncriminal	77	23
Criminal	35	65

74.7% of all subjects into criminal and noncriminal categories (Table). The false-positive rate (noncriminals incorrectly classified as criminals) was 23.1%.

Potential Mediating Effects of Social and Academic Factors

There was a tendency for criminals-to-be to be of lower socioeconomic status, to be older, to reside in areas of higher crime, and to be of lower academic ability. However, Spearman's correlations between these social variables and psychophysiological measures were near zero (age: $r = -.05$, range, .05 to $-.16$; socioeconomic status: $r = -.04$, range, .05 to $-.13$; and residence: $r = -.03$, range, .07 to $-.16$) and consequently seem unable to account for the observed psychophysiological differences. Furthermore, one-way MANOVAS indicated that school status was unrelated to all measures of arousal ($P > .22$). Consequently, these social and academic factors do not appear to be important mediators of the crime-arousal relationship.

COMMENT

These analyses indicate that adult criminals had significantly lower electrodermal, cardiovascular, and cortical arousal than noncriminals when measured at the age of 15 years. One exception was the nonsignificant findings for SCLs. The finding of lower NS-SCRs, which replicated across hands, may have produced stronger evidence for electrodermal underarousal than SCLs because the latter are more influenced by non-ANS factors, such as local peripheral conditions, thickness and hydration of the stratum corneum, and the number and size of sweat glands.[29] Consequently, NS-SCRs may be a more sensitive measure of ANS arousal than SCLs.

These psychophysiological differences between criminals and noncriminals do not appear to be mediated by social and demographic differences since all relationships between these variables and arousal measures were small and non-significant. Nevertheless, other environmental factors not measured in this study may mediate the relationship between crime and arousal, since there is evidence from other studies that social factors (eg, social class) interact with biological factors in the development of antisocial behavior.[15,31] Results of the present study merely demonstrate that several social factors do not mediate this relationship. It must also be emphasized that the present psychophysiological findings do not negate the role of social factors in the development of criminality. Indeed, the facts that several social variables were related to criminality status and that they were independent of measures of underarousal indicate the importance of social variables in explaining criminal behavior.

Although the sample size of 101 is not large, it seems unlikely that these findings are due to sampling bias or chance. Data loss for criminality status due to emigration from the country is expected to be negligible. Subjects were sampled from schools in a way to provide a representative sample of the normal population of 15-year-old adolescents.[27] Nevertheless, the sample will not contain highly antisocial adolescents held in special schools, hospitals, and detention units. This sampling bias would be expected to reduce the number of severely criminal subjects in the sample and consequently reduce the power of the analyses and the likelihood of obtaining significant differences. Since EEGs, HRLs, and NS-SCRs are uncorrelated in the total sample (mean $r = -.04$; range, .05 to $-.06$) and have been found to be unrelated in other studies,[32] the finding of lower arousal on all three measures may be considered to provide three independent replications of the association between arousal and criminality. The criminal group has also been found to give fewer skin conductance and heart rate responses to orienting stimuli than noncriminals (A.R., P.H.V., M.W., unpublished data, January 1989). These findings are consistent with autonomic underarousal in the criminal group and further indicate that the present findings are robust.

To our knowledge, this is the first study, prospective or nonprospective, to provide evidence for the role of both ANS and CNS underarousal in the development of criminal behavior, and to our knowledge, it is the first study to implicate electrodermal *and* cardiovascular *and* cortical under-arousal in any psychopathological condition. While prospective research cannot conclusively demonstrate causal relationships, the present findings are nevertheless consistent with the view that ANS and CNS underarousal may play a role in the development of criminal behavior. The strength of these results may be in part due to the fact that the data were prospectively collected. As noted earlier, prospective studies have several advantages over previous studies that utilize institutionalized samples; to date, all have produced positive findings.

The measures of arousal used here are in part genetically determined.[9-11] The resting HRL, for example, has been reported to have heritabilities that range from 0.37[34] to 0.82.[10] The finding of reduced arousal in criminals is therefore consistent with the view that the genetic predisposition to criminality may find its expression through ANS and CNS underarousal. At a neuroanatomical level, the fact that the levels of all three physiological systems are reduced suggests that a diffuse brain-stem arousal mechanism may be dysfunctional in criminals. Some independent support for this view is derived from the finding of a slower brain-stem evoked response latency in waves II, III, and IV in patients with an antisocial personality disorder relative to noncriminal controls.[35] Further pathophysiological studies testing this hypothesis would clearly be desirable.

The discriminant function analysis indicated that 74.7% of subjects could be correctly classified on the basis of arousal variables. Although a false-positive rate of 23.1% was observed, this is relatively small given the statistical difficulties in predicting events with low base rates. It is clear that psychophysiological factors alone cannot fully predict criminal behavior. In conjunction with social and psychological variables, however, measures of ANS and CNS underarousal may facilitate the early prediction of later antisocial behavior and elucidate the etiological basis to criminality.

Reduced electrodermal, cardiovascular, and cortical arousal may not be the only psychophysiological mechanisms involved in criminality. In particular, there is clear evidence that evoked potential measures are related to crime and antisocial behavior.[35,37] Furthermore, psychophysiological factors alone cannot fully account for the development of criminal behavior, and it is possible that the genetic predisposition to criminality manifests itself in ways other than through ANS and CNS underarousal. Nevertheless, the present results at least implicate underarousal in the development of criminal behavior and may hold implications for the early prediction of criminal behavior.

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