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BIOSOCIAL CORRELATES OF COGNITIVE ABILITIES

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Summary. The children in the cohort followed by the National Child Development Study were tested for cognitive ability at the age of eleven, and the influence of a number of biological and social variables was sought on the results of tests of reading, mathematics, verbal and non-verbal abilities. Reading relates strongly to social class, birth order and parental age, suggesting strong social influences upon it, but it is also related to height and acquired myopia, suggesting biological influences. Mathematics ability relates to social class and parental age, but not to birth order, but its relationship with height, birthweight and maternal smoking suggests biological effects. Verbal ability and non-verbal ability have relatively few correlates apart from sex and region. It appears that different cognitive abilities show different relationships to social, biological and personal variables.

Introduction

Differences in cognitive abilities have been shown to be related to social variables (such as social class), personal attributes (such as height, blood group and the presence of acquired myopia) and to family variables (such as parental age and birth order). However, there has been a tendency to examine these variables in isolation, without considering either the possible effects which other apparently independent but actually correlated variables, or their interactions, may have upon the results (Vernon, 1979). The present study evaluates the concurrent effects of a large number of variables and their interactions upon reading, mathematical, verbal and non-verbal ability test scores. As the scores on these four tests inter-correlate highly, it also attempts to separate those components which are specific to each of the tests, and analyses them separately.

Method

The data are those obtained by the National Child Development Study (NCDS). This study commenced as the Perinatal Mortality Survey, and involved all children

Table 1. Transformations* used to convert the raw scores, R, V, N and M to the normalized scores, R_n, V_n, N_n and M_n

	R	V	N	M
a	0·99	1·23	1·195	0·754
b	0·0004	0·0005	0·000225	0·014
c	−15·747	−46·169	−38·398	−7·972
d	−15·564	−46·168	−38·471	−7·973
e	2·379	0·423	0·810	2·510

* Of the form $X_n = e(X^a + b(X^a + c)^3 + d) + 100$.

born in Britain during the week 3rd–9th March, 1958. At that time detailed obstetric data were collected on each child (Butler & Bonham, 1963; Butler & Alberman, 1969). The surviving children, together with any others in the same birth cohort entering the country after that date, were followed up in 1965 (NCDS I) and again at the age of 11 in 1969 (NCDS II). At the age of 11 the children were given four tests of cognitive ability; a reading test (R), a mathematics test (M), and tests of verbal (V) and non-verbal (N) ability (Fogelman *et al.*, 1978; Adams, Ghodsian & Richardson, 1976). A total of 13,808 children completed all four tests. As the distribution of each test was both skewed and kurtotic, non-linear transformations were used to normalize each distribution with a mean of 100 and a standard deviation of fifteen (Table 1). These scores are symbolized R_n, V_n, N_n and M_n.

The influence of the following variables upon the ability tests was examined: social class (C) of the father when the child was aged 11, classified according to the Registrar General's classification, high social status being indicated by a score of 1; order of birth into the family (B); sex of the child (S); mean parental age at the time of the child's birth (PA); difference in age of the two parents (PD); standard administrative region in which the child lived in 1969 (Reg); height at the age of 11 (H); the presence of acquired myopia (AM); handedness (HD) and eye-dominance (ED); birth weight (BW); number of obstetric complications (BC); maternal history of smoking during pregnancy (CS); and the ABO and rhesus blood groups of the mother (BG). Of the children, 7172 had complete information on all of the relevant variables and only these children have been included in the analysis.

Results

A canonical correlation analysis of the four ability tests (R_n, V_n, N_n, M_n) with these predictor variables produced four highly significant orthogonal canonical variates ($\chi^2_{168} = 2440{\cdot}8$, $\chi^2_{123} = 800{\cdot}8$, $\chi^2_{80} = 346{\cdot}39$ and $\chi^2_{39} = 127{\cdot}1$, in order of removal). As this result implied that the predictor variables have different effects upon the four ability scales, the data were further studied to elucidate these effects using, for ease of interpretation, image factor analysis to derive five oblique scores.

Four of the scores were derived by multiple regression, each being the residual of that score after the removal of effects due to the other three abilities (Table 2).

Table 2. Inter-correlations between the transformed scores R_n, V_n, N_n and M_n (A), multipliers and constants used to derive R_3, V_3, N_3, M_3 and G from R_n, V_n, N_n and M_n (B) and the correlations between the five derived scores (C)

A. Correlation matrix		R_n	V_n	N_n	M_n	
	R_n	1·000	0·747	0·650	0·756	
	V_n	0·747	1·000	0·804	0·785	
	N_n	0·650	0·804	1·000	0·748	
	M_n	0·756	0·785	0·748	1·000	
B. Multipliers and constants						Constant
	R_3	1·0	−0·4043	0·0065	−0·4436	−15·7677
	V_3	−0·2711	1·0	−0·4407	−0·2517	−3·7135
	N_3	0·0056	−0·5691	1·0	−0·3050	−13·0715
	M_3	−0·3513	−0·2974	−0·2790	1·0	−7·3126
	G	0·1929	0·3172	0·2324	0·2603	0·0
C. Correlation matrix		G	R_3	V_3	N_3	M_3
	G	1·0	−0·129	−0·173	−0·143	−0·154
	R_3	−0·129	1·0	−0·330	0·006	−0·394
	V_3	−0·173	−0·330	1·0	−0·500	−0·273
	N_3	−0·143	0·006	−0·500	1·0	−0·291
	M_3	−0·154	−0·394	−0·273	−0·291	1·0

All correlations based on $N = 13{,}808$.

For example, the residual obtained after regressing R_n upon V_n, N_n and M_n (symbolized by R_3) may be interpreted as a measure of a child's relative reading ability, given his particular performance upon the other three tests; V_3, N_3 and M_3 are calculated similarly. The scores R_3, V_3, N_3 and M_3 represent the specific variances of each of the tests when analysed by the method of image factor analysis (Guttman, 1953; Harman, 1976). The common variance of the tests was partitioned into orthogonal components. Ninety-one per cent of this variance was accounted for by a single factor. This factor is readily interpreted as a general ability factor, which we have called G, and comprises the fifth derived score used with R_3, V_3, N_3 and M_3 in the main analysis. The justification for using these scores, as opposed to, say, the four principal components of the raw scores, is that they are simpler to interpret. The small remaining portion of the common variance will not be discussed further.

The significance of a predictor was found by examining the extra variance contributed by it after the main effects of all other predictors had been removed. For many of the variables quadratic, cubic and quartic terms of the predictor variable were used, the significance of higher order terms being tested after lower order terms for that predictor had already been fitted. In total 42 main effect terms were fitted. The significance of interaction terms was determined similarly; that is, after all main effects had been fitted. A total of 104 interactions was examined. Because of computing limitations the interaction terms were tested in two blocks, one with 53 terms (mostly involving class, birth order and sex with the other variables) and the other with 51 terms (the remaining variables).

Main effects

The main effects accounted for a highly significant amount of the variance of each of the five derived scores ($F (42,7179) = 39{\cdot}57, 9{\cdot}11, 10{\cdot}65, 5{\cdot}16$ and $7{\cdot}35$ for G, R_3, V_3, N_3 and M_3 respectively, $P < 0{\cdot}001$ in each case). The addition of the two blocks of interactions produced no signficant increase in the explained variance of any of the derived scores.

Social class

Figure 1 shows the effect of social class upon G, R_3, V_3, N_3 and M_3, after removing effects due to other predictor variables. There are clear and highly significant effects of social class upon G, R_3, N_3 and M_3. However, there is no effect of social class upon V_3, a result which is unexpected in view of the findings of other studies that verbal ability varies with social class (Higgins, 1976).

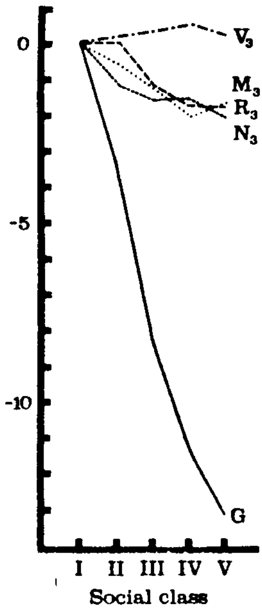

Fig. 1. Fitted fourth-order polynomial effects of social class upon the five ability scales, relative to social class I. Linear trends are significant for G, R_3, N_3, and M_3 ($F\ 1{,}7132 = 480{\cdot}56$, $P \ll 0{\cdot}001$; $28{\cdot}92$, $P \ll 0{\cdot}001$; $10{\cdot}24$, $P < 0{\cdot}01$ and $27{\cdot}73$, $P \ll 0{\cdot}001$ respectively) but not for V_3 ($F\ 1{,}7132 = 1{\cdot}27$, NS). Quadratic, cubic and quartic polynomials are significant for G ($F\ 1{,}7131 = 16{\cdot}51$, $P < 0{\cdot}001$; $F\ 1{,}7130 = 4{\cdot}89$, $P < 0{\cdot}05$ and $F\ 1{,}7129 = 4{\cdot}63$, $P < 0{\cdot}05$ respectively). Higher-order polynomials are not significant for R_3, V_3, N_3, and M_3 ($F\ 3{,}7129 = 2{\cdot}60$, NS; $0{\cdot}36$, NS; $1{\cdot}60$, NS and $1{\cdot}36$, NS respectively).

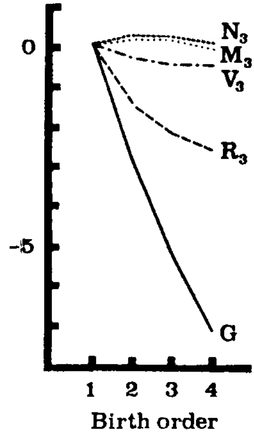

Fig. 2. Fitted third-order polynomial effects of birth order on the five ability scales, relative to first-born children. Linear trends are significant for G and R_3 (F 1,7131 = 308·03, $P \ll 0{\cdot}001$; 69·707, $P \ll 0{\cdot}001$ respectively), but not for V_3, N_3, and M_3 (F 1,7131 = 0·94, NS; 0·35, NS; 0·31, NS respectively). For G the quadratic trend was also significant (F 1,7130 = 3·88, $P < 0{\cdot}05$) but not the cubic trend (F 1,7129 = 0·97, NS), whilst for R_3 the quadratic trend was not significant (F 1,7130 = 3·79, NS), but the cubic trend was (F 1,7129 = 4·83, $P < 0{\cdot}05$). For V_3, N_3 and M_3 there was no evidence of a linear trend (F 1,7131 = 0·94, NS; 0·34, NS; and 0·31, NS, respectively) or of higher-order trends (F 2,7129 = 1·22, NS; 1·37, NS; and 0·83, NS respectively).

Birth order

Birth order effects upon ability have been discussed extensively (Zajonc, Markus & Markus, 1979), although there are problems in reconciling discrepant studies. Figure 2 shows that birth order primarily relates to G and R_3, and has no discernible effect upon V_3, N_3, and M_3. This observation may well explain some of the discrepancies between studies. In the present study birth order and family size are confounded.

Parental age

Parental age has been reported to relate to cognitive ability (Zybert, Stein & Belmont, 1978). Figure 3 shows a clear monotonic relation between the average parental age at the birth of the child and the G score. Two separate factors appear to contribute to this trend, first a linear trend of R_3 upon age, and, secondly, a quadratic trend of M_3 upon age. There are no effects of parental age upon V_3 and N_3.

The effect of the difference in parental ages was also considered. On average the father was 2·94 years older than the mother. There is a small but significant linear trend for children to have a higher G score in families in which the mother is the older parent (Fig. 4). In addition there is a small quadratic relation between parental age difference and N_3, deviations from the 'typical' pattern producing a small decrease in N_3.

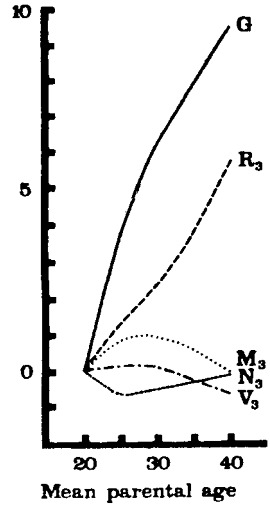

Fig. 3. Fitted fourth-order polynomial effects of mid-parental age upon the five ability scales. For G the linear, quadratic and cubic trends are significant (F 1,7132 = 186·04, $P \ll 0{\cdot}001$; F 1,7131 = 6·45, $P < 0{\cdot}05$; F 1,7130 = 6·63, $P < 0{\cdot}05$ respectively) while the quadratic trend is not significant (F 1,7129 = 0·03, NS). For R_3 the linear trend is significant (F 1,7132 = 121·22, $P \ll 0{\cdot}001$), while the linear trends are not significant for V_3, N_3 and M_3 (F 1,7132 = 1·52, NS; 0·21, NS; and 1·32, NS respectively). The quadratic trend is significant for M_3 (F 1,7131 = 12·51, $P < 0{\cdot}001$) but not for R_3, V_3 and N_3 (F 1,7131 = 1·634, NS; 0·004, NS; and 1·649, NS respectively). Higher-order polynomials are not significant for R_3, V_3, N_3 and M_3 (F 2,7129 = 0·89, NS; 2·13, NS; 1·09, NS; and 0·57, NS respectively).

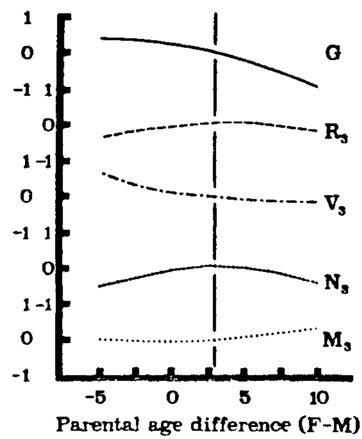

Fig. 4. Fitted second-order polynomial effects of difference in parental ages on the five ability scales, relative to the mean parental age difference. The linear trend is significant for G (F 1,7130 = 9·43, $P < 0{\cdot}01$), but not for R_3, V_3, N_3 or M_3 (F 1,7130 = 0·04, NS; 2·67, NS; 1·00, NS; and 1·73, NS respectively). The quadratic trend is significant for N_3 (F 1,7129 = 7·63, $P < 0{\cdot}01$) but not for G, R_3, V_3, and M_3 (F 1,7129 = 2·55, NS; 1·71, NS; 2·30, NS; and 1·33, NS, respectively).

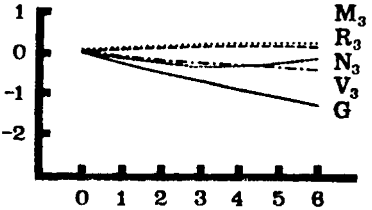

Fig. 5. Fitted second-order polynomial effects of the number of obstetric complications on the five ability scales, relative to no obstetric complications. The linear trend is significant for G (F 1,7130 = 5·01, $P < 0·05$) but not for R_3, V_3, N_3, and M_3 (F 1,7130 = 0·0, NS; 2·35, NS; 0·03, NS; and 0·15, NS). Quadratic trends for G, R_3, V_3, N_3 and M_3 are not significant (F 1,7129 = 0·39, NS; 0·26, NS; 0·003, NS; 1·63, NS; and 0·24, NS, respectively).

Obstetric complications

It is commonly suggested that obstetric complications result in decreased cognitive abilities (Vernon, 1979). Figure 5 shows the relation between the number of complications occurring, either antenatally, intra-partum or immediately post-partum (McManus, 1981), and the ability scores. No attempt was made to

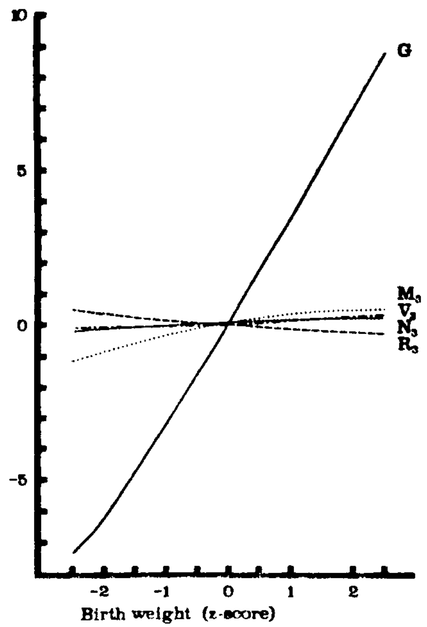

Fig. 6. Fitted second-order polynomial effects of birth weight upon the five ability scales, relative to the mean birth weight of the population. The linear trends of G and M_3 are significant (F 1,7130 = 39·87, $P \ll 0·001$; 8·71, $P < 0·01$), while those of R_3, V_3 and N_3 are not significant (F 1,7130 = 0·00, NS; 2·35, NS; 0·03, NS respectively). The quadratic trends on G, R_3, V_3, N_3 and M_3 are all non-significant (F 1,7129 = 0·39, NS; 0·26, NS; 0·003, NS; 1·63, NS; and 0·24, NS, respectively).

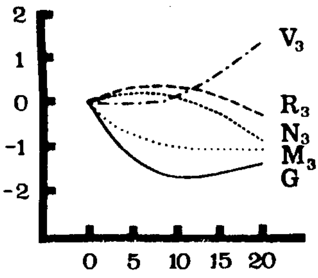

Fig. 7. Fitted third-order polynomial effects of the number of cigarettes smoked per day by the mother during pregnancy upon the five ability scales. The linear trends of G, V_3, and M_3 are all significant (F 1,7131 = 19·35, $P < 0{\cdot}001$; 8·13, $P < 0{\cdot}01$; 19·05, $P \ll 0{\cdot}001$ respectively), while the effects on R_3 and N_3 are not significant (F 1,7131 = 0·05, NS; 1·96, NS). The quadratic trend of V_3 is significant (F 1,7130 = 4·81, $P < 0{\cdot}05$) whilst the quadratic trends of G, R_3, N_3, and M_3 are not significant (F 1,7130 = 2·46, NS; 1·23, NS; 2·77, NS; and 0·75, NS). The cubic trends of G, R_3, V_3, N_3, and M_3 are not significant (F 1,7129 = 1·82, NS; 0·49, NS; 0·02, NS; 0·02, NS; and 1·66, NS respectively).

weight complications in terms of severity. There is an inverse relation between G and the number of complications which is only just statistically significant, but otherwise no association was found.

Before testing the significance of this effect, the effects of low birth weight and of maternal cigarette smoking had been removed from the data. Figure 6 shows that low birth weight relates significantly to lower G and also to M_3. Figure 7 shows that maternal cigarette smoking also relates very significantly to G and to M_3. These effects are independent of each other and of obstetric complications since each effect was tested for significance after removal of all other effects. It thus appears that maternal smoking and low birth weight both relate to a relative disability not only in general but also on the mathematics score, M_3.

Sex differences

It is frequently suggested that there are sex differences in cognitive style, girls being thought to be better on tasks involving verbal skills, and boys better on tasks involving visuo-spatial concepts (Maccoby & Jacklin, 1975). Figure 8 shows that girls scored higher on G and V_3; boys however scored better on R_3, N_3 and M_3.

Lateralization

Sex differences in cognitive style have been related to different patterns of lateralization of function (Hutt, 1972). Reading deficits have also been related to unusual patterns of eye–hand dominance (Corballis & Beale, 1976), and left-handers in general have been suggested to be of lower overall ability (Hardyck, Petrinovich & Goldman, 1976). Figure 8 shows scores as a function of hand and eye laterality. Left-handers score significantly lower on G than do right-handers, as

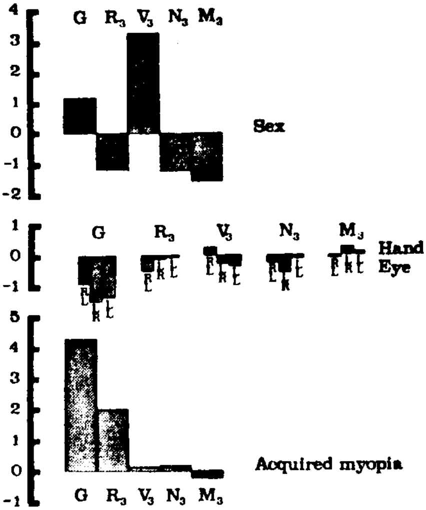

Fig. 8. Top: Fitted effect of being female upon the five ability scales relative to the male scores. The effects of G, R_3, V_3, N_3, and M_3 are all significant (F 1,7129 = 16·58, $P < 0{\cdot}001$; 30·31, $P \ll 0{\cdot}001$; 342·31, $P \ll 0{\cdot}001$; 36·52, $P \ll 0{\cdot}001$; and 67·46, $P \ll 0{\cdot}001$ respectively).

Centre: Fitted effects of hand and eye dominance upon the five ability scales relative to right-handed, right-eyed individuals. RL indicates right-handed, left-eyed, etc. For G the effect of handedness alone is significant (F 1,7131 = 6·91, $P < 0{\cdot}01$) as also is the effect of eyedness after removal of the effects due to handedness (F 1,7130 = 6·16, $P < 0{\cdot}05$). For G there is no evidence of an eye by hand interaction (F 1,7129 = 1·18, NS). There is no evidence of an effect of hand and eye dominance pattern upon R_3, V_3, N_3, and M_3 (F 3,7129 = 1·22, NS; 1·02, NS; 0·74, NS; and 0·13, NS, respectively).

Bottom: Fitted effect of the presence of acquired myopia upon the five ability scales, relative to individuals who do not fit into this category. For G and R_3 the effects are significant (F 1,7129 = 35·62, $P \ll 0{\cdot}001$; 13·41, $P < 0{\cdot}001$ respectively). For V_3, N_3, and M_3 the effect is not significant (F 1,7129 = 0·06, NS; 0·06, NS; 0·21, NS, respectively).

also do the left-eyed. However there is no evidence of a statistical interaction between the two (crossed-dominance). There is no effect of hand or eye dominance upon R_3, V_3, N_3, or M_3. Furthermore there is no evidence of hand × eye × sex interactions upon any of the five scales (see below). Differences between right- and left-handers cannot be attributed to the influence of a small group of severely retarded left-handers (Annett & Turner, 1974), since removal of the lowest 5% of the population from the analysis did not affect the result.

Acquired myopia

Children with acquired myopia have been shown elsewhere (Karlsson, 1973), as well as in a previous analysis of the present data (Peckham, Gardiner & Goldstein, 1977), to have a greater score on ability scales. Figure 8 confirms this finding and shows that the effect is restricted to G and R_3.

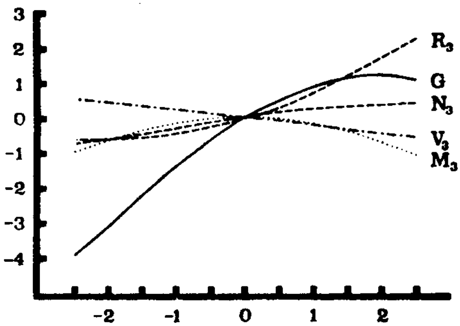

Fig. 9. Fitted third-order polynomial effects of height upon the five ability scales, relative to the ability of those of average height. The linear trends of G, R_3, V_3, and N_3 are significant (F 1,7031 = 47·86, $P \ll 0{\cdot}001$; 27·58, $P < 0{\cdot}001$; 5·64, $P < 0{\cdot}05$; 5·24, $P < 0{\cdot}05$ respectively), while the effect upon M_3 is not significant (F 1,7031 = 0·07, NS). The quadratic effects of G, R_3, and M_3 are significant (F 1,7030 = 7·44, $P < 0{\cdot}01$; 5·03, $P < 0{\cdot}05$; 8·42, $P < 0{\cdot}01$ respectively), while the quadratic effects of V_3 and N_3 are not significant (F 1,7030 = 0·01, NS; 0·11, NS). Cubic effects of G, R_3, V_3, N_3, and M_3, are all non-significant (F 1,7029 = 1·03, NS; 0·08, NS; 0·05, NS; 0·32, NS; and 0·00, NS, respectively).

Height

Taller children are, on average, of greater intellectual ability (Tanner, 1962), although it has been suggested that this relationship may be a reflection of social class differences (Rutter & Madge, 1976). Figure 9 shows the five ability scales as a function of height, after controlling for all other main effects. There are clear linear trends of G and R_3, upon height. However, there is also a significant quadratic relation between height and M_3, children of average height showing greater mathematical ability than children of more extreme height.

Regional differences

Regional differences in ability have been discussed (Rutter & Madge, 1976; Lynn, 1979a). Figure 10 shows the effects of region upon the five ability scales. Differences between regions in R_3, V_3, N_3, and M_3 are all highly significant at 1%, and for G the differences are significant at the 5% level. These differences may reflect differences in teaching practices (Rutter & Madge, 1976), but they also raise the possibility, as suggested by Lynn (1979b), of a true cline, particularly for V_3 and M_3. The ABO blood group frequencies show a cline in Britain, and the ABO blood groups have also been suggested to relate to ability (Gibson *et al.*, 1973). Although blood group information was not collected for the children in our sample, there were data on maternal ABO and rhesus blood groups (Fig. 11) but these show no effects of maternal blood groups upon child's ability.

Size of effects

Although the effects of the predictor variables reported here are highly significant in statistical terms, many of them are small in real terms. All together,

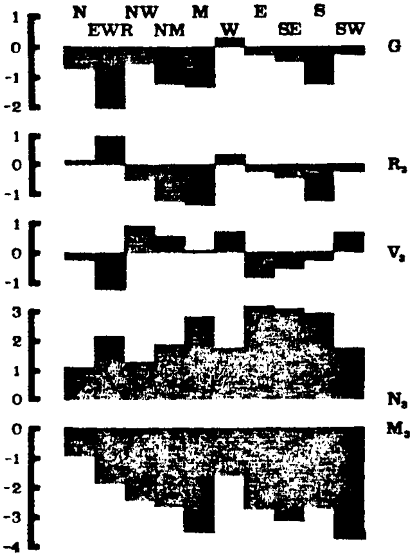

Fig. 10. Fitted effects of the region in which the child was living at age 11, upon the five ability scores, relative to children living in Scotland. Effects are significant for G, R_3, V_3, N_3 and M_3 (F 10,7129 = 2·11, $P < 0{\cdot}01$; 3·41, $P < 0{\cdot}001$; 5·19, $P < 0{\cdot}001$; 10·73, $P \ll 0{\cdot}001$; and 12·74, $P \ll 0{\cdot}001$ respectively). N = North, EWR = East–West Riding; NW = North-West; NM = North Midlands, M = Midlands; W = Wales; E = East; SE = South-East (including London); S = South; SW = South-West.

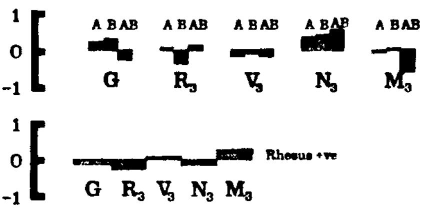

Fig. 11. Top: Fitted effects of maternal ABO blood group upon the five ability scores of the child, relative to those of blood group O.

Bottom: Fitted effect of maternal rhesus blood group upon the five ability scales, relative to those of blood group rhesus negative. Taken overall there is no effect of blood group upon G, R_3, V_3, N_3, and M_3 (F 4,7129 = 0·24, NS; 0·43, NS; 0·21, NS; 1·18, NS; and 0·51, NS, respectively).

using the main effects model, they account for 19·4% of the variance of G, and 5·9%, 6·8%, 3·7% and 5·1% respectively of the variances of R_3, V_3, N_3 and M_3. These figures, particularly for the residual scores, are low. Though they may in part be accounted for by the fact that our correlation matrices were not corrected for reliability, which would particularly affect the residual scores, nevertheless the proportion of accounted variance in G is similar to that found in other studies (Vandenberg & Kuse, 1980, unpublished; Firkowska *et al.*, 1978).

Maternal cigarette smoking: a causal analysis

Demonstrations of a correlation between maternal smoking and subsequent diminished ability in the child fail to distinguish the hypothesis that smoking directly damages the fetus, from the hypothesis that smokers are a constitutionally separate group of individuals who differ from non-smokers, and hence have different sorts of children (Eysenck, 1965). An attempt was made to distinguish between these hypotheses by further examining the data on the children of those classified as smokers, ex-smokers or non-smokers during pregnancy.

For each child, five scores were calculated, being the residuals of G, R_3, V_3, N_3 and M_3 after the main effects of the other predictor variables had been removed (designated as G_r, R_r, V_r, N_r and M_r). Maternal smoking habits were further classified on the basis of the mother's description of her own smoking habits in a questionnaire completed at the time of the child's birth (Butler & Alberman, 1969). The children were divided into three groups, according to whether the mother smoked no cigarettes (A), 1–9 (B) or 10+ (C) cigarettes from the 4th month of pregnancy onwards. Those children in group A were further sub-divided into two groups, A_1 whose mothers said that they did not smoke prior to pregnancy, and A_2 whose mothers said that they did smoke prior to pregnancy (i.e. they were ex-smokers). No information was available as to subsequent smoking history. Differences between the four groups were analysed by a one-way analysis of variance, planned comparisons being used to test specific hypotheses.

Table 3. Effect of maternal cigarette smoking: mean scores and F-statistics of each of the groups on the five variables

	Smoking prior to/during pregnancy		Variable G_r	R_r	V_r	N_r	M_r	*n*
Group								
A	—	0	0·4519	−0·0686	−0·0634	0·0349	0·2556	4943
B	—	1–9	−0·8540	0·3143	−0·2962	0·1878	−0·3404	1041
C	—	10+	−1·116	0·0097	0·5295	−0·3145	−0·7627	1187
A_1	0	0	0·5293	−0·2137	−0·0508	0·0689	0·3452	4405
A_2	1+	0	−0·1820	1·119	−0·1665	−0·2427	−0·4777	538
Population standard deviations			11·7988	8·9054	7·2165	8·2355	7·8833	7171
Statistical testing								
F (3,7167)			8·384	4·116	2·885	1·016	7·847	
P			<0·0001	0·0064	0·0345	0·3847	<0·0001	

Planned comparisons	Coefficients A_1	A_2	B	C		G_r	R_r	V_r	N_r	M_r
Comparison 1	1	1	0	−2	t	2·965	1·348	−2·395	1·307	2·396
					P	0·003	0·178	0·017	0·191	0·016
Comparison 2	−1	−1	4	−2	t	−0·900	0·258	−1·966	0·748	0·261
					P	0·368	0·796	0·052	0·454	0·794
Comparison 3	1	−1	0	0	t	1·322	−3·280	0·351	0·828	2·289
					P	0·186	0·001	0·725	0·408	0·022

The mean scores and the F-statistics of each of the groups on the five variables (Table 3) show that for G_r, R_r and M_r there are highly significant differences between groups, and V_r shows marginally significant differences. There is a significant linear effect of smoking during pregnancy upon G_r (comparison 1) as has been reported previously (Royal College of Physicians, 1977; Fogelman, 1980), and also upon M_r. A significant trend in the opposite direction is found for V_r. There were no significant quadratic trends (comparison 2). Examining groups A_1 and A_2 only, there are significant effects of pre-pregnancy smoking upon R_r and M_r (comparison 3).

Interactions

Simply to dismiss the interactions as not significant by the global test (Table 4) ignores the theoretical problems inherent in such analysis. In effect it assumes that all of the interactions assessed were of equal practical or theoretical importance, and hence were weighted equally. But results from other workers may lead to prediction of a specific interaction. The analysis of interactions was therefore extended, the significance of a single interaction being examined by fitting it immediately after the main effects. Tables 5 and 6 show the significant values of individual interaction terms fitted in this way, quadratic and higher-order terms being fitted hierarchically after lower-order terms. Of a total of 520 fitted effects, 16 were 'significant' at the 5% level, and 6 at the 1% level, the expected values under a chance hypothesis being 26 and 5 respectively. Again the pattern of significant interactions which emerges is not noteworthy and suggests as the best interpretation that for these data no interaction terms are necessary.

Discussion

The present analysis suggests that different cognitive abilities show different relationships to social, biological and personal variables. Relative reading ability (R_3) relates strongly to social class, birth order, and parental age, suggesting strong social influences upon it; nevertheless it is also related to height and to acquired myopia, suggesting biological influences. Relative mathematics ability (M_3) relates to social class and parental age, but not to birth order, suggesting some weaker social influences upon it. However, the effect of height, and in particular of birth weight and maternal smoking suggest important biological effects. Relative verbal ability (V_3), is not related to social class or birth order, and the only strong effects upon it are those of sex and region, as well as a smaller effect of maternal smoking. Relative non-verbal ability (N_3) has relatively few correlates apart from social class, sex and region effects, and a small quadratic effect of difference in parental age. The general ability score (G) relates to almost all of the variables, and only maternal blood groups are noticeable for their lack of an effect.

The interpretation of the effects of maternal cigarette smoking upon subsequent child ability is complex. That maternal smoking during pregnancy has a direct causal effect upon later childhood ability is suggested by the relationship between overall ability (G_r), and smoking during pregnancy, and the absence of an effect of smoking before pregnancy. This explanation cannot however be applied to M_r;

Table 4. Analysis of variance for testing global effects of interaction terms

		G		R_3		V_3		N_3		M_3	
	df	SS	F	SS	F	SS	F	SS	F	SS	F
Main effects model	42	232016·3	39·574	30548·4	9·119	23407·1	10·655	14795·3	5·166	19243·9	7·353
Residual	7129	995125·7	$P < 0{\cdot}001$	568605·8	$P < 0{\cdot}001$	372861·5	$P < 0{\cdot}001$	486119·2	$P < 0{\cdot}001$	444254·8	$P < 0{\cdot}001$
Main effects + interactions set A	95	238316·2		35383·6		26875·1		18689·9		23587·5	
Residual	7076	988825·7		563770·6		369393·6		482224·6		439911·2	
Interactions set A effect	53	6299·9	0·8506 NS	4835·2	1·145 NS	3468·0	1·253 NS	3894·6	1·078 NS	4343·6	1·318 NS
Main effects + interactions set B	93	239448·3		34283·4		25773·1		18774·1		22612·6	
Residual	7078	987693·7		564870·8		370495·6		482140·5		440886·1	
Interactions set B effect	51	7432·0	1·044 NS	3735·0	0·917 NS	2366·0	0·886 NS	3978·8	1·146 NS	3368·7	1·060 NS

Table 5. Significance† (t test) of the individual interaction of set A terms

Interaction	Other interactions fitted prior to fitting	t G	t R_3	t V_3	t N_3	t M_3
$C_1 \times B_1$		0·60	−0·64	0·74	0·41	−0·99
$C_1 \times S$		−1·54	−1·26	1·43	2·07	−1·65
$C_1 \times HD$		−1·20	0·09	−1·60	1·06	1·34
$C_1 \times ED$	$C_1 \times HD$	−0·54	−2·36	0·19	−0·20	2·11
$C_1 \times HD \times ED$	$C_1 \times HD$; $C_1 \times ED$	−0·22	−0·56	0·03	−1·02	1·50
$C_1 \times Reg$		0·41*	1·25*	1·13*	1·22*	1·88*
$C_1 \times BC_1$		−1·14	−0·84	0·83	0·35	0·05
$C_1 \times H_1$		−0·24	0·73	0·32	−0·73	−0·16
$C_1 \times H_2$	$C_1 \times H_1$	−0·83	−0·77	2·30	−0·67	−0·84
$C_1 \times AM$		0·64	−1·82	−0·03	0·18	1·07
$C_1 \times CS_1$		1·44	0·14	0·90	−0·53	−1·39
$C_1 \times PA_1$		0·56	0·30	−0·96	−0·43	0·93
$C_1 \times PA_2$	$C_1 \times PA_1$	0·51	0·15	−0·35	1·10	−1·03
$C_1 \times PD_1$		−1·44	−0·21	1·20	0·11	−0·52
$C_1 \times BW_1$		1·13	−0·57	−2·13	−0·22	2·46
$B_1 \times S$		1·48	0·32	0·80	−0·66	−1·31
$B_1 \times HD$		0·35	−0·96	−0·92	0·32	1·35
$B_1 \times ED$	$B_1 \times HD$	−0·92	−1·69	1·08	0·54	0·19
$B_1 \times HD \times ED$	$B_1 \times HD$; $B_1 \times ED$	0·34	0·64	−0·88	0·64	−0·33
$B_1 \times BC_1$		1·22	−2·45	0·40	−0·41	1·36
$B_1 \times H_1$		1·12	0·28	−0·75	−0·34	0·33
$B_1 \times H_2$	$B_1 \times H_1$	0·06	−0·50	−0·19	0·70	−0·04
$B_1 \times AM$		−0·66	1·11	−1·15	0·89	−0·13
$B_1 \times CS_1$		0·35	−0·95	−2·58	3·12	0·59
$B_1 \times PA_1$		1·25	2·00	−0·98	−0·23	−1·02
$B_1 \times PA_2$	$B_1 \times PA_1$	−1·62	0·71	1·44	0·27	−1·61
$B_1 \times PD_1$		−0·50	−0·21	0·45	−0·32	0·24
$B_1 \times BW_1$		−0·66	−1·46	1·01	−0·47	0·89
$S \times HD$		−0·26	0·14	1·15	0·68	0·66
$S \times ED$	$S \times HD$	1·94	−1·65	1·29	−0·08	−0·99
$S \times HD \times ED$	$S \times HD$; $S \times ED$	1·06	−0·70	−0·52	−0·07	0·68
$S \times BC_1$		0·36	−0·37	0·28	1·30	−1·41
$S \times H_1$		−0·12	1·80	−2·39	1·45	−0·14
$S \times H_2$	$S \times H_1$	0·09	−1·13	1·45	−0·51	−0·23
$S \times AM$		−1·63	0·39	0·96	−0·58	−0·03
$S \times CS_1$		−0·75	−0·44	1·45	1·47	−2·23
$S \times PA_1$		1·82	−0·09	0·27	−0·60	−0·63
$S \times PA_2$	$S \times PA_1$	0·99	0·38	−0·17	−0·75	0·06
$S \times PD_1$		0·24	0·23	0·60	0·21	−1·19
$S \times BW_1$		0·47	0·99	−0·30	−2·30	1·40
$CS_1 \times PA_1$		0·41	−1·89	−2·77	3·19	1·50
$CS_1 \times PA_2$	$CS_1 \times PA_1$	−1·06	−0·38	0·99	−1·24	0·93
$CS_1 \times PD_1$		−0·11	0·83	1·65	−0·35	−2·16
$CS_1 \times BW_1$		−0·30	1·42	−0·33	−1·17	0·41

* Value of F with 10,7119 df.

† See text for description of assessment: single underline, $P < 0{\cdot}05$; double underline, $P < 0{\cdot}01$.

Table 6. Results of t-tests of significance for the individual interaction terms of set B

Interaction	Other interactions fitted prior to fitting	t G	R_3	V_3	N_3	M_3
HD × BC_1		−0·89	−0·06	0·20	1·12	−0·75
ED × BC_1	HD × BC_1	−0·59	−1·03	−0·75	2·16	0·00
HD × ED × BC_1	HD × BC_1; ED × BC_1	0·51	−0·21	0·30	0·33	−0·73
HD × H_1		0·20	−1·41	2·22	−1·95	0·42
ED × H_1	HD × H_1	1·14	−0·97	0·42	0·15	−0·39
HD × ED × H_1	HD × H_1; ED × H_1	−0·51	1·48	−0·22	1·11	−1·77
HD × AM		−1·13	−0·18	1·90	0·31	−1·66
ED × AM	HD × AM	0·77	0·83	0·12	1·26	−2·41
HD × ED × AM	HD × AM; ED × AM	0·17	−1·87	0·39	0·18	0·87
HD × CS_1		−1·24	−0·96	−0·72	0·84	1·47
ED × CS_1	HD × CS_1	−1·36	−0·91	−1·42	1·22	1·92
HD × ED × CS_1	HD × CS_1; ED × CS_1	−0·44	0·77	−1·41	0·05	1·10
HD × PA_1		−0·33	−0·15	−0·18	−0·05	0·56
ED × PA_1	HD × PA_1	−0·66	0·50	0·44	0·78	−1·30
HD × ED × PA_1	HD × PA_1; ED × PA_1	−0·89	1·04	−1·00	1·66	−0·84
HD × PD_1		−1·47	0·63	0·54	−0·11	−0·26
ED × PD_1	HD × PD_1	−0·08	−0·80	0·00	0·34	0·41
HD × ED × PD_1	HD × PD_1; ED × PD_1	0·95	0·56	−0·34	0·86	−1·39
HD × BW_1		0·44	0·29	1·38	−0·25	−1·78
ED × BW_1	HD × BW_1	0·00	−0·09	0·12	−1·48	1·33
HD × ED × BW_1	HD × BW_1; ED × BW_1	−1·58	0·18	1·77	1·08	−2·30
BC_1 × H_1		−0·50	−0·03	−0·41	−0·31	1·10
BC_1 × H_2	BC_1 × H_1	0·50	−0·06	−1·01	0·78	0·18
BC_1 × AM		1·49	1·12	−1·53	0·35	−0·35
BC_1 × CS_1		0·03	−0·69	−0·13	1·62	−0·80
BC_1 × PA_1		−0·05	−1·92	−0·35	0·94	1·16
BC_1 × PA_2	BC_1 × PA_1	0·51	−0·13	−0·38	0·73	−0·42
BC_1 × PD_1		−0·18	1·97	−1·81	−0·52	0·94
BC_1 × BW_1		−0·87	−1·48	0·05	−0·34	1·95
H_1 × AM		−1·90	0·81	0·74	0·32	−0·80
H_2 × AM	H_1 × AM	−1·15	−1·52	0·38	0·97	0·55
H_1 × CS_1		1·31	−1·19	0·29	−0·74	0·67
H_2 × CS_1	H_1 × CS_1	−1·69	1·11	−0·16	0·56	−0·38
H_1 × PA_1		0·73	−0·74	−0·46	1·00	−0·19
H_2 × PA_1	H_1 × PA_1	−0·19	0·55	−0·45	1·22	−0·99
H_1 × PA_2	H_1 × PA_1	1·90	0·05	1·54	−1·50	−1·36
H_2 × PA_1	H_1 × PA_1; H_1 × PA_2; H_2 × PA_1	0·50	−0·60	0·67	−0·29	−0·30
H_1 × PD_1		−0·12	0·88	−0·83	−0·91	1·08
H_2 × PD_1	H_1 × PD_1	−1·15	1·11	−0·71	0·82	−0·30
H_1 × BW_1		0·53	−0·09	1·48	−0·94	−0·98
H_2 × BW_1	H_1 × BW_1	0·55	0·54	1·60	−1·05	−1·54
AM × CS_1		1·21	−0·84	−2·21	3·20	−0·46
AM × PA_1		0·65	−0·29	0·11	−0·48	0·23
AM × PA_2	AM × PA_1	0·98	−0·78	0·58	0·50	0·97
AM × PD_1		1·62	−1·52	−0·82	−0·40	1·09
AM × BW_1		0·40	0·65	−0·49	−0·40	0·15
PA_1 × PD_1		−2·58	1·03	−0·35	0·75	0·18
PA_2 × PD_1	PA_1 × PD_1	1·45	1·03	0·02	0·31	0·16
PA_1 × BW_1		0·66	−0·13	0·27	−1·46	0·83
PA_2 × BW_1	PA_1 × BW_1	0·12	1·11	0·74	1·19	0·58
PD_1 × BW_1		−0·86	−0·62	0·86	−1·09	1·03

mathematical ability is relatively worse in the children both of those who smoke during pregnancy and of those who smoke before pregnancy, and the effect may be explicable in constitutional terms. For relative reading ability constitutional and perhaps also motivational factors cannot be ruled out, since R_r (which is sensitive to variables such as birth order and parental age), is higher in the children of ex-smokers than non-smokers. This suggests that the motivation necessary for giving up smoking may perhaps be reflected in greater parental involvement in the child's reading, or alternatively that constitutional differences between smokers and non-smokers also relate to reading ability.

Despite our worries that a global assessment of the significance of interaction terms might be too conservative and conceal interactions of theoretical significance (such as, for example, interactions between social class and either birth order or cigarette smoking) these fears seem to be groundless given the pattern of interactions found using our more liberal criterion. Nevertheless, as stated earlier, some interactions may well be significant to other researchers who are viewing effects *a priori* rather than *a posteriori*.

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