EARLY ENVIRONMENTAL INFLUENCES ON THE DEVELOPMENT OF INTELLIGENCE

THOMAS McKEOWN M.D. Ph.D. D.Phil. F.R.C.P.
R. G. RECORD M.D. Ph.D.
Department of Social Medicine
University of Birmingham

1 Some problems associated with investigation of intelligence
2 Obstetric influences
3 Birth-weight and duration of gestation
4 Birth order and maternal age
5 Evidence from twins
6 Nature of postnatal influences
7 Conclusion
References

The literature related to the study of intelligence is vast and even in an appraisal of environmental influences some restriction must be imposed. This discussion will be focused on intelligence in the general population and so far as possible will exclude variation in association with recognized causes or abnormalities. In particular it will exclude mental subnormality.

The last restriction presents difficulties, since the subnormal comprise not only patients with associated pathological conditions, but also others identified solely on the basis of their social or intellectual impairment. Some of the latter undoubtedly belong to the general population, and to the extent that they are excluded the study of intelligence is deficient. The justification for omitting the subnormal from the present discussion is that, in an examination of environmental influences on the variation of intelligence in the general population, omission of some individuals from the lower end of the distribution is less serious than inclusion of those whose defect is known to be associated with other abnormalities.

1. Some Problems Associated with Investigation of Intelligence

What tests measure. This much debated question has been discussed by Vernon (1966) in terms which would probably be acceptable to biologists if not to all psychologists. Tests measure reliably neither genetically determined ability nor a generalized capacity attributable to the interaction of inheritance and environment. Specific tests measure specific abilities, and the relation of any single test or group of tests to the abstraction of general intelligence is still obscure. The results depend to a considerable extent on motivation and social influences, and, in multiple choice tests at least, can be improved by coaching.

Nature and nurture. Attempts to partition variance in test scores between inheritance and environment raise the familiar difficulties well discussed by Hogben (1933) and, more recently, by Waddington (1957). Estimates of the extent to which intelligence is genetically determined have little meaning, unless they are made within a very specific and limited environment.

Types of population examined. Most investigations of environmental influences, and particularly of early influences, on intelligence are based on one of two approaches whose differences account to a considerable extent for different conclusions. In one, children are observed from birth and the populations examined are likely to include some with associated abnormalities, particularly when propositi are in a sub-sample identified, for example, by low birth-weight. In the other approach, the population consists of children of school age and usually excludes those not educated in normal schools. As a basis for investigation of environmental influences on the distribution of intelligence in the general population both methods have their limitations: the first because it tends to include some with associated pathological conditions; and the second because it commonly excludes children at the lower end of the distribution.

Loss of propositi. For investigation of some environmental influences a very large number of children must be examined. If they are identified at birth and followed for a number of years there is inevitably a considerable loss by removal or death from the original population, and it becomes important to establish the representativeness of those who remain.

Sample size. The circumstances of investigation sometimes force observers to accept samples that are too small to give conclusive results. In studies on twins, for example, it is particularly difficult to raise the number of observations to an adequate level.

2. Obstetric Influences

The obstetric influences referred to are abnormalities of pregnancy and delivery; they do not include duration of gestation, birth-weight, birth order and maternal age, which are considered later.

Barker (1966a) investigated 607 subnormal children from a population of 73 687 single births and concluded: "Recognized abnormalities of pregnancy and delivery seemed to play little part in determining subnormality." There have been few reports on the relation of obstetric influences to intelligence in a general population. Shipe, Vandenberg & Brooke Williams (1968) observed no difference at 30 months of age in mean scores from two tests (for social maturity and intelligence) between children who had experienced difficulties at birth and matched controls. However, the number of pairs examined (33) was small and the fact that scores were also unrelated to family size provides some grounds for reservation. A different result was reported by Hardy (1965) who found that measured intelligence at four years of age was substantially reduced in children exposed to adverse perinatal influences, such as toxaemia, antepartum haemorrhage, precipitate labour and breech delivery.

Barker & Edwards (1967) examined the relation between obstetric complications and verbal reasoning scores recorded at the selective examination of approximately 50000 11-year-old children (11+ examination). They showed that, within a total population, comparisons according to type of presentation, type of labour and the presence or absence of antenatal diseases may be very misleading, mainly because of variation by birth rank. For example, the incidence of toxaemia in first-born children was twice that in later born; and verbal reasoning scores are also higher for first than for later children. This difficulty was largely overcome by comparing the scores

Downloaded from http://bmb.oxfordjournals.org at University of Bedfordshire on August 9, 2010

of children exposed to obstetric complications with those of their sibs. From this evidence it was concluded that impaired performance was associated with toxaemia, occipitoposterior presentation and delivery in an ambulance. However, the differences were not great, and do not suggest that obstetric influences of this type contribute substantially to the variation of measured intelligence in a general population.

3. Birth-Weight and Duration of Gestation

Low birth-weight may be due to early onset of labour and/or retarded fetal growth, and for many purposes, including the study of intelligence, it is desirable to consider it together with duration of gestation. However, since it is only recently that this point has been widely recognized, there is a large literature devoted exclusively to the study of intelligence and birth-weight and a small one concerned with intelligence and duration of gestation. It will therefore be necessary to comment separately on these related themes before attempting to bring them together.

Birth-weight. The significance of the method of inquiry is nowhere more apparent than in the study of birth-weight; most investigations have been concerned, not with the relation between weight and intelligence in a general population of births, but with the possible influence of weight in sub-samples identified on the basis of low birth-weight. Many of these samples contain children with recognized pathological conditions and some include twins as well as single births; probably all of those identified at very low weights contain a proportion of abnormal births, whether or not they are recognized as such at the time of selection. The results of these inquiries will be considered first, although their bearing on the more general problem of the relation between weight and intelligence is far from clear.

Much attention has been given to children regarded as "premature" on the basis of birth-weight of 2500 g (5½lb) or less. Results in the earlier literature reviewed by Benton (1940) were contradictory, but Wiener (1962) examined a further eighteen studies which provided evidence that intelligence was lower for "premature" babies than for those of heavier birth-weight.

A number of investigators have considered children with very low birth-weights and most have concluded that their intelligence was lower than that of heavier "premature" children (Harper, Fischer & Rider, 1959; Drillien, 1961; Lubchenco, Horner, Reed, Hix, Metcalf, Cohig, Elliott & Bourg, 1963). However, Douglas (1960), in his follow-up of the children provided by the survey in 1946 of social and economic aspects of pregnancy and childbirth, undertaken by a Joint Committee of the Royal College of Obstetricians and Gynaecologists and the Population Investigation Committee (1948), found no variation in intelligence among "premature" children according to birth-weight. McDonald (1964) examined infants of less than 4 lb birth-weight and concluded that after exclusion of those with cerebral palsy, blindness, deafness and intelligence quotients (I.Q.) below 50, the I.Q. of the remainder was about the same as for normal births.

A different approach was used by Asher & Roberts (1949) who made a retrospective study of children in ordinary schools and found no difference in birth-weight according to type of school—primary, secondary grammar or secondary modern. However, birth-weight was low in children attending schools for the educationally subnormal and this observation was confirmed by Barker (1966b) and Churchill, Neff & Caldwell (1966).

In summary, mean birth-weight is undoubtedly low in subnormal children. On the evidence so far considered, its relation to intelligence in a general population from which the subnormal and others with recognized abnormalities have been excluded is less clear; results from examinations of intelligence according to birth-weight are inconsistent with one another and with the results shown in the report (Asher & Roberts, 1949) of birth-weight of schoolchildren according to a rather crude classification of intelligence.

These conclusions give a greatly simplified impression of a complex and confusing literature and it may be useful to mention some reasons for the contradictions and ambiguities. Investigations have used samples of varying size and composition; many were too small to give convincing results and some included a considerable proportion of recognized abnormalities. Different methods have been employed to estimate intelligence and the age at assessment has varied between a few months after birth and adolescence. But perhaps the main reason for ambiguity is the difficulty of separating the effect of birth-weight on intelligence from that of related variables such as social class, birth order and duration of gestation. Attempts have been made to eliminate some of these influences by comparison with matched controls, but Douglas (1960) questioned the reliability of this method. Fortunately many of the difficulties can be resolved by sib comparisons and twin studies, and the results from these investigations will be discussed later.

Duration of gestation. There have been few examinations of the relation between duration of gestation and intelligence. Baird (1959) concluded that "... there is no clear indication that within wide limits premature expulsion from the uterus does the foetus any serious harm." However, Davie (1969) assessed the reading ability of a sub-sample of children in the 1958 British Perinatal Mortality Survey, comprising 11000 children in English schools, and reported that the proportion of poor readers was about 24% in those born before 37 or after 43 weeks' gestation, compared with 17% in those born between 37 and 43 weeks. The relation between duration of gestation and intelligence will be discussed more fully in the next section where account is also taken of birth-weight.

Birth-weight and duration of gestation. Although the importance of considering birth-weight with duration of gestation has been recognized for nearly twenty years, there have been few reports in which the two variables have been examined together in relation to intelligence. Using this approach Douglas (1956), Baird (1959), Bazsó, Karmazsin & Gelei (1964) and McDonald (1964) concluded that intelligence was lower for children whose low weight was due to retarded fetal growth than for those for whom it was explained by a short period of gestation. However, Eaves, Nuttall, Klonoff & Dunn (1970) found no difference between scores of the two groups after the first year.

With verbal reasoning scores measured in the 11+ examination, Record, McKeown & Edwards (1969b) were able to assess the relation of intelligence to birth-weight and duration of gestation in a population of 41 534 single births. Their results, summarized in Table I, show (i) that scores increase with increasing birth-weight and (ii) that children born early or late have somewhat lower scores than those from pregnancies of average duration. However, their observations on 5042 sib pairs provide little evidence of variation in scores in relation to

Downloaded from http://bmb.oxfordjournals.org at University of Bedfordshire on August 9, 2010

TABLE I. Mean verbal reasoning scores according to birth-weight and duration of gestation (based on 41 534 children who took the 11+ examination)

Duration of gestation (weeks)	Birth-weight (kg)					
	2.0–	2.5–	3.0–	3.5–	4.0–	4.5 and over
34–	97	98	94	—	—	—
36–	97	98	98	98	—	—
38–	97	99	101	102	102	—
40–	95	98	100	102	103	103
42–	—	96	98	101	102	104
44 and over	—	—	97	98	—	—

Means are given for cells with more than 100 observations.

For the whole series the mean score was 100.2 and the standard deviation was 15

birth-weight and duration of gestation in the same families. This indicates that the substantial variation in a general population of births is explained by differences between rather than within families.

Several influences undoubtedly contribute to the relation to birth-weight, particularly social class, since both measured intelligence and birth-weight are lower for poor than for well-to-do children. The possibility could not be excluded that large birth-weight differences may have an independent relationship to scores. But there must be doubt about the "normality" of births of very low weight, and for normal single births variation in intelligence due to differences in birth-weight and duration of gestation is probably very small.

The sib data examined by Record *et al.* (1969b) also suggest that the observed relation between intelligence and duration of gestation (Table I) may be largely attributable to errors in recording the onset of pregnancy. Children of 40–41 weeks' gestation had considerably lower scores when their sibs were reported to be born very early or very late than when they were said to be of average duration.

4. Birth Order and Maternal Age

Birth order and family size. There have been some investigations of birth order but many more of the related variable of family size. The extensive literature reviewed by Nisbet (1953) and Anastasi (1956), among others, leaves no doubt that measured intelligence is negatively correlated with family size, and this observation has been the starting-point for much speculation concerning the contribution of inheritance and environmental influences to intelligence. In particular, it was suggested that intelligence was declining (Burt, 1946), a conclusion challenged on theoretical grounds (Penrose, 1950) and not confirmed by results so far reported (Cattell, 1950; Emmett, 1950; Maxwell, 1961).

Among many problems associated with interpretation of the relation between fertility and measured intelligence the following are particularly important:

i. whether the fertility differentials observed over a limited range of intelligence (usually in children in ordinary schools) are acceptable for the full range in a total population. Penrose (1955) suggests that they are not and believes that biological mechanisms maintain stability, as in the case of other characters such as stature and weight;

ii. the extent to which test scores are environmentally determined. We have already referred to the difficulty of partitioning variance between inheritance and environment, except over a very limited environmental range. The evidence does not make it possible to say to what extent the variation in intelligence according to family size is attributable to inheritance or to environmental influences;

iii. the extent to which the variation in intelligence observed in a population (usually of schoolchildren) is due to differences within rather than between families. A negative correlation between sibship size and intelligence would result if birth order and intelligence were also negatively correlated.

Evidence concerning the relation of intelligence to birth order is mainly of two kinds: observations on the ordinal position of individuals identified in adult life as successful (for example by entry to *Who's who*); and comparisons of school performance or other indices between children from the same family. The data from both sources (reviewed by Altus, 1966; and Warren, 1966) leave a good deal to be desired: much of the material was highly selected; sibships compared were usually incomplete, so that it is uncertain whether observed differences are due to the ordinal position or size of family identified by it; and when intelligence of sibs was compared they were often tested at different ages. If any general conclusion can be drawn it is that first born probably have some advantage over later born in measured intelligence in childhood and in success in later life. But some investigations have given results which either are not in accord with this conclusion (Jones, 1954; Tabah & Sutter, 1954) or suggest that it is valid only in certain circumstances (Douglas, 1964).

Maternal age. In most investigations of intelligence, family size and birth order, little attention has been given to the possible significance of maternal age, and results from the few reports (summarized by Locke & Goldstein, 1937) are inconsistent. Roberts (1947) and Moore (1968) concluded that age was unimportant but an investigation in Aberdeen showed that test scores increase with increasing mother's age (Illsley, 1967). However, since this report also considered birth order it will be discussed below.

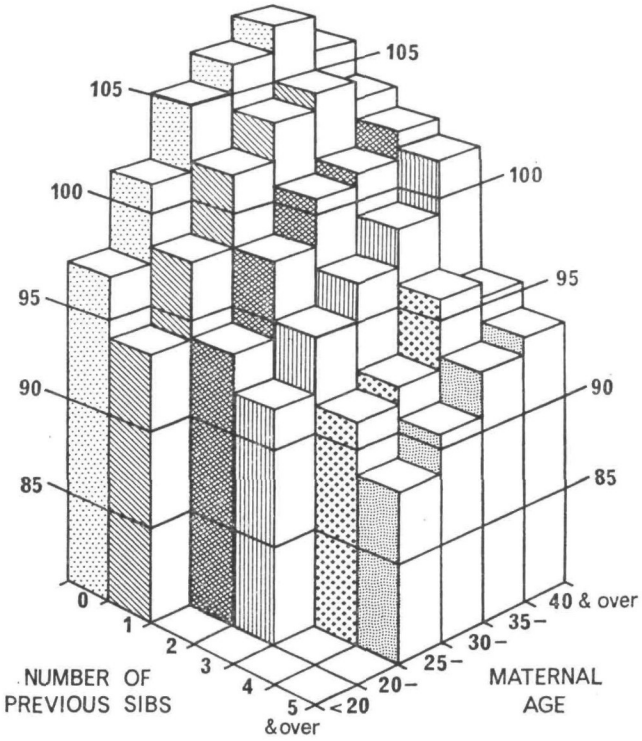
Birth order and maternal age. In view of the high correlation between birth order and maternal age, it is essential to examine intelligence simultaneously in relation to both variables. Two recent surveys have met this requirement: one in Aberdeen based on about 11000 children (Illsley, 1967); and one in Birmingham, based on nearly 50000 children (Record, McKeown & Edwards, 1969a). The findings leave no doubt that, in a general population of children, measured intelligence decreases with increasing birth order and increases with increasing maternal age. The results are illustrated in fig. 1.

The Birmingham data included approximately 4700 fraternities with two or more children born within the period of study; mean scores were one point lower for the later than for the earlier sibs, and Record *et al.* (1969a) concluded that "... the striking association of measured intelligence with maternal age and birth order in a general population of children is determined mainly by differences between rather than within families."

The question remains as to the explanation of the large differences shown in fig. 1. Illsley (1967) noted that the

Downloaded from http://bmb.oxfordjournals.org at University of Bedfordshire on August 9, 2010

FIG. 1. Mean verbal reasoning scores according to age of mother at birth of child and number of previous sibs



distribution of test scores by maternal age and birth order corresponds to that of postnatal death-rates, determined essentially by socio-economic influences, rather than to that of stillbirth rates which reflect a "physiological or obstetric influence".

Both surveys gave substantial differences in test scores for different social groups. Since distribution of children by mother's age and birth order is to some extent a distribution according to social class, the relation of scores to the two variables in a population of births is largely a reflection of the social class differences.

On this evidence only, no conclusion could be reached about the origin of the class variation. But the small differences related to birth order between children in the same families (Record *et al.* 1969a), whose environment is relatively uniform and for whom no question of genetic variation arises, suggest that the much larger differences which exist between families also reflect in part postnatal experience.

5. Evidence from Twins

Monozygotic and dizygotic twins. Estimates have been made of the correlation between test scores of twins from different types of pairs and this evidence has been used to partition variance between hereditary and environmental influences. Perhaps the only conclusion that has emerged consistently is that the correlation is higher for monozygotic (about 0.8–0.9) than for dizygotic pairs. Correlations reported for dizygotic pairs are variable but in general somewhat higher than for normal sibs (Newman, Freeman & Holzinger, 1937). Estimates have also been made of the correlation in pairs whose zygosity was not determined; they range from 0.6 to 0.8 for like-sex pairs and from 0.4 to 0.6 for unlike-sex pairs (Mehrotra & Maxwell, 1949; Tabah & Sutter, 1954; Record, McKeown & Edwards, 1970).

Interpretations of such findings differ almost as widely as the estimates. In one or two cases, conclusions were thought to be supported by supplementary evidence, for example by comparisons between twins reared together and apart (Burt, 1966), and between like-sex and unlike-sex dizygotic pairs (Stocks & Karn, 1933). Unfortunately the results, considered as a whole, are by no means consistent, and it is still not clear to what extent the higher correlation between monozygotic than between dizygotic twins is attributable to their more uniform environment.

Differences between twins and single births. Estimates of measured intelligence of twins leave no doubt that mean values are about 5 points lower than those for single births (Mehrotra & Maxwell, 1949; Tabah & Sutter, 1954; Sandon, 1957; Drillien, 1961). From observations on nearly 1000 twins, Barclay & Maxwell (1950) concluded that the difference could not be accounted for by variation in social class, family size or overcrowding. Using test scores in the 11+ examination for approximately 2000 twins and 50000 single births, Record *et al.* (1970) found that the differences were not explained by differences in distribution by maternal age and birth order or by birth-weight and duration of gestation. They were also not accounted for by the increased risks associated with monozygosity or with delivery of the second twin. These results do not support the suggestion by Churchill (1965) that the lower twin scores are due to prenatal influences.

Record *et al.* (1970) examined data for 148 twins whose co-twins were stillborn or died within four weeks after birth. Mean scores were only a little lower than for single births and it was concluded that the handicapping of twins is due to postnatal rather than prenatal influences.

6. Nature of Postnatal Influences

There is little doubt that the postnatal environment has an important influence on the development of intelligence. It is much less certain what features of the environment are involved.

Attempts to relate impairment of intellectual ability to severe malnutrition in childhood (Stoch & Smythe, 1967) are unconvincing, and animal experiments, such as the demonstration that underfed young rats perform badly in maze learning (Winick, 1969), are of doubtful relevance.

Many educational psychologists believe that normal mental development is largely dependent on verbal communication between parent and child in early life. It has been suggested that at least some of the impaired ability of children from large families can be explained by their relative lack of parental attention, and that the retarded development of orphanage children, children who speak two languages, deaf children, and twins is due to restricted verbal experience (Nisbet, 1953; Lewis, 1963).

Twins are of particular interest in this context. It has been shown that they lag behind single children in verbal development (Day, 1932; Davis, 1937; Luria & Yudovich, 1959; Willerman & Churchill, 1967), possibly because they tend to communicate non-verbally with each other and have less association with adults than single children have (McCarthy, 1954). This interpretation is still speculative, but the observa-

Downloaded from http://bmb.oxfordjournals.org at University of Bedfordshire on August 9, 2010

tion that twins brought up together perform less well in intelligence tests than twins who have lost their co-twin in early life (Record *et al.* 1970) leaves no doubt about the retarding effect of one twin upon the other.

7. Conclusion

The respective contributions of hereditary and environmental influences to variation in measured intelligence are still unknown. Correlation between scores is higher for monozygotic than for dizygotic twins, but it is not clear to what extent the difference is attributable to their more uniform environment. Moreover, there are theoretical objections to the partitioning of variance between inheritance and environment except within a limited environmental range.

Prenatal environmental influences appear to contribute little to the variation in intelligence in a general population from which those with recognized defects are excluded. There is little relationship to abnormalities of pregnancy or labour. Differences in test scores associated with duration of gestation are probably due to errors in recording the date of the last menstrual period, and those related to birth-weight are very small when comparison is restricted to sibs or twins. But the most convincing evidence that prenatal influences have little effect on measured intelligence is the observation that twins separated from their co-twin at or soon after birth have scores which are little lower than those of single births, in spite of their retarded fetal growth, short period of gestation and increased risks during birth.

There are very large variations in intelligence in a general population of births in relation to maternal age and birth order (fig. 1); but these are due to differences between rather than within families, for there is little variation according to birth rank between sibs. The differences between families, reflected in the age–birth-order distribution of measured intelligence, are due largely to substantial variation in intelligence in relation to social class.

To what extent the class differences are genetically determined is still obscure. But the observation that the mean intelligence score of twins raised together is 5 points lower than that of twins separated at birth leaves little doubt about the substantial contribution of postnatal environmental influences.

REFERENCES

Altus, W. D. (1966) *Science, N.Y.* **151,** 44
Anastasi, A. (1956) *Psychol. Bull.* **53,** 187
Asher, C. & Roberts, J. A. F. (1949) *Br. J. soc. Med.* **3,** 56
Baird, D. (1959) *J. Obstet. Gynaec. Br. Emp.* **66,** 743
Barclay, G. & Maxwell, J. (1950) *Popul. Stud.* **4,** 333
Barker, D. J. P. (1966a) *Br. J. prev. soc. Med.* **20,** 15
Barker, D. J. P. (1966b) *Br. J. prev. soc. Med.* **20,** 58
Barker, D. J. P. & Edwards, J. H. (1967) *Br. med. J.* **3,** 695
Bazsó, J., Karmazsin, L. & Gelei, K. (1964) In: Øster, J., ed. *International Copenhagen congress on the scientific study of mental retardation, Copenhagen, August 7–14, 1964,* vol. 1, p. 411. [Statens Åndssvageforsorg, Copenhagen]
Benton, A. L. (1940) *Am. J. Orthopsychiat.* **10,** 719
Burt, C. (1946) *Intelligence and fertility: the effect of the differential birthrate on inborn mental characteristics.* (Occasional Papers on Eugenics, No. 2.) The Eugenics Society and Hamish Hamilton, London
Burt, C. (1966) *Br. J. Psychol.* **57,** 137
Cattell, R. B. (1950) *Eugen. Rev.* **42,** 136
Churchill, J. A. (1965) *Neurology, Minneap.* **15,** 341
Churchill, J. A., Neff, J. W. & Caldwell, D. F. (1966) *Obstet. Gynec., N.Y.* **28,** 425
Davie, R. (1969) In: Butler, N. R. & Alberman, E. D., ed. *Perinatal problems: the second report of the 1958 British perinatal mortality survey,* chapter 16. Livingstone, Edinburgh
Davis, E. A. (1937) *The development of linguistic skill in twins, singletons with siblings, and only children from age five to ten years.* The University of Minnesota Press, Minneapolis
Day, E. J. (1932) *Child Dev.* **3,** 179
Douglas, J. W. B. (1956) *Br. med. J.* **1,** 1210
Douglas, J. W. B. (1960) *Br. med. J.* **1,** 1008
Douglas, J. W. B. (1964) *The home and the school: a study of ability and attainment in the primary school.* MacGibbon & Kee, London
Drillien, C. M. (1961) *Archs Dis. Childh.* **36,** 233
Eaves, L. C., Nuttall, J. C., Klonoff, H. & Dunn, H. G. (1970) *Pediatrics, Springfield,* **45,** 9
Emmett, W. G. (1950) *Popul. Stud.* **3,** 324
Hardy, J. B. (1965) In: Osler, S. F. & Cooke, R. E., ed. *The biosocial basis of mental retardation,* p. 35. The Johns Hopkins Press, Baltimore, Md
Harper, P. A., Fischer, L. K. & Rider, R. V. (1959) *J. Pediat.* **55,** 679
Hogben, L. (1933) *Nature and nurture.* Williams & Norgate, London
Illsley, R. (1967) In: Platt, Lord & Parkes, A. S., ed. *Social and genetic influences on life and death,* p. 29. (A symposium held by the Eugenics Society, September 1966.) Oliver & Boyd, Edinburgh
Joint Committee of the Royal College of Obstetricians and Gynaecologists and the Population Investigation Committee (1948) *Maternity in Great Britain.* Oxford University Press, London
Jones, H. E. (1954) In: Carmichael, L., ed. *Manual of child psychology,* 2nd ed., p. 631. Wiley, New York & London
Lewis, M. M. (1963) *Language, thought and personality in infancy and childhood.* Harrap, London
Locke, N. M. & Goldstein, H. (1937) *J. Psychol.* **3,** 89
Lubchenco, L. O., Horner, F. A., Reed, L. H., Hix, I. E., jr, Metcalf, D., Cohig, R., Elliott, H. C. & Bourg, M. (1963) *Am. J. Dis. Child.* **106,** 101
Luria, A. R. & Yudovich, F. I. (1959) Simon, J., ed. *Speech and the development of mental processes in the child.* Staples Press, London
McCarthy, D. (1954) In: Carmichael, L., ed. *Manual of child psychology,* 2nd ed., p. 492. Wiley, New York & London
McDonald, A. D. (1964) *Br. J. prev. soc. Med.* **18,** 59
Maxwell, J. (1961) *The level and trend of national intelligence: the contribution of the Scottish mental surveys.* University of London Press, London
Mehrotra, S. N. & Maxwell, J. (1949) *Popul. Stud.* **3,** 295
Moore, T. (1968) *Hum. Dev.* **11,** 1
Newman, H. H., Freeman, F. N. & Holzinger, K. J. (1937) *Twins: a study of heredity and environment.* University of Chicago Press, Chicago, Ill.
Nisbet, J. D. (1953) *Family environment: a direct effect of family size on intelligence.* (Occasional Papers on Eugenics, No. 8.) The Eugenics Society and Cassell, London
Penrose, L. S. (1950) *Br. J. Psychol.* **40,** 128
Penrose, L. S. (1955) *Proc. R. Soc.* B, **144,** 203
Record, R. G., McKeown, T. & Edwards, J. H. (1969a) *Ann. hum. Genet.* **33,** 61
Record, R. G., McKeown, T. & Edwards, J. H. (1969b) *Ann. hum. Genet.* **33,** 71
Record, R. G., McKeown, T. & Edwards, J. H. (1970) *Ann. hum. Genet.* **34,** 11
Roberts, J. A. F. (1947) *Br. J. Psychol. statist. Sect.* **1,** 35
Sandon, F. (1957) *Jl R. statist. Soc.* (Ser. A) **120,** 440
Shipe, D., Vandenberg, S. & Williams, R. D. Brooke (1968) *Child Dev.* **39,** 861
Stoch, M. B. & Smythe, P. M. (1967) *S. Afr. med. J.* **41,** 1027
Stocks, P. & Karn, M. N. (1933) *Ann. Eugen.* **5,** 1
Tabah, L. & Sutter, J. (1954) *Ann. hum. Genet.* **19,** 120
Vernon, P. E. (1966) In: Meade, J. E. & Parkes, A. S., ed. *Genetic and environmental factors in human ability,* p. 3. (A symposium held by the Eugenics Society, September–October 1965.) Oliver & Boyd, Edinburgh
Waddington, C. H. (1957) *The strategy of the genes: a discussion of some aspects of theoretical biology.* Allen & Unwin, London
Warren, J. R. (1966) *Psychol. Bull.* **65,** 38
Wiener, G. (1962) *J. nerv. ment. Dis.* **134,** 129
Willerman, L. & Churchill, J. A. (1967) *Child Dev.* **38,** 623
Winick, M. (1969) *J. Pediat.* **74,** 667

Downloaded from http://bmb.oxfordjournals.org at University of Bedfordshire on August 9, 2010