RM. 25

Psychological Medicine, 1981, **11**, 485–496
Printed in Great Britain

Handedness and birth stress

I. C. McMANUS[1]

From the Psychological Laboratory, Cambridge

SYNOPSIS The relationship between left-handedness and birth complications was studied. No evidence of any association was found in either 2 retrospective studies, or 1 large prospective study.

INTRODUCTION

Bakan (1971) proposed that left-handedness might be a result of 'neurological insult associated with pre-natal or delivery factors'. At that stage his only substantive evidence was a relation between handedness and birth order, those birth ranks associated with a higher incidence of perinatal mortality (1,4+) having a higher frequency of left-handedness than the lower-risk birth ranks (2,3). It is perhaps also worth noting that the U-shaped relation between parity and perinatal mortality is itself at present a subject of controversy, parity being confounded with birth-interval and socio-economic variables in most studies (Bakketeig & Hoffman, 1979). Bakan *et al.* (1973) attempted a slightly more direct approach to the problem, asking students whether there had been any complications during their own birth. Left-handers reported more birth stress, as also did both left- and right-handers with a sinistral family history as compared with the appropriate control group without a sinistral family history. The incidence of left-handedness was also raised in the children of older mothers (greater than 30 years), another high-risk group for perinatal morbidity and mortality. Bakan *et al.* (1973) proposed that familial tendencies to left-handedness might be a secondary result of a familial tendency to birth stress. Extrapolating further from their hypothesis, they suggested that 'the frequency of left-handedness ... might serve as a general index of the prevalence of birth-related neurological insult' (p. 365). They also implied that left-handedness should be more common in lower socio-economic groups, although the opposite to this was later claimed by Bakan (1977).

Bakan (1975), without presenting any additional data, took his hypothesis even further. Birth stress, and by direct implication left-handedness, 'may be related to a variety of genetic or environmental factors, such as maternal physique, parity, nutrition, drug ingestion, smoking, or even pain sensitivity which may influence the amount of anaesthetic used in delivery' (p. 201). Left-handedness was regarded as 'an indication of neurological insult associated with pregnancy and birth. It is something to be reduced rather than tolerated... In fact handedness deviation in a group indicates that the group is at risk for neuropathological conditions. Preventive interaction in such groups could pay tremendous dividends, both economically and in the reduction of suffering.' Clearly such a theory, if true, is of the greatest importance, both for neuropsychology and for obstetrics.

Bakan's theory has not always been unopposed. Hubbard (1971) and Schwartz (1977) were unable to replicate Bakan's birth-order effect. Bakan (1977) attempted to account for these discrepancies in terms of socio-economic differences between the samples. He also presented another sample of data which showed the birth-order effect at the 0·05 level. Further evidence cited by him in favour of his hypothesis was that Leviton & Kilty (1976) had found a 'dose-related effect': that is, an especially high incidence of left-handedness was found in birth ranks of 6 and higher, who could be supposed to have suffered a greater 'dose' of cerebral insult. Despite this apparent sophistication, the authors omitted to state the sample size within each birth rank, and also published no statistical tests; a

[1] Address for correspondence: Dr I. C. McManus, Department of Psychiatry, St Mary's Hospital, Harrow Road, London, W9 3RL; and Department of Psychology, Bedford College, Regent's Park, London, NW1.

reconstruction of these data (by assuming that particular parities occurred at the same frequency as in the general population) suggests that there is no statistical significance, the sample being far too small to find effects of the size postulated ($\chi^2 = 9{\cdot}58$, df = 6, NS).

Hicks *et al.* (1978*a*) also failed to find a birth-order effect. Hicks *et al.* (1978*b*) pointed out that a compilation of all the studies in the literature still failed to show a significant birth-order effect of the type postulated by Bakan. As a result of my own unpublished studies on Cambridge University undergraduates, I have also come to the same conclusion.

The only published replication of the study by Bakan *et al.* (1973) is that of Schwartz (1977), who failed to find any significant effect. My own data from two surveys of Cambridge University undergraduates (described elsewhere; McManus, 1979) are shown briefly in Tables 1 and 2.

Table 1. *The relation between handedness and a history of birth stress (or birth complications), shown separately for Surveys I and II*

	Handedness			
	Right	Left	No.	%L
Survey I				
Birth complications				
−	721	108	829	13·0
+	95	12	107	11·2
	$\chi^2 = 0{\cdot}14$, df = 1, $P = 0{\cdot}708$			
Survey II				
Birth complications				
−	803	129	932	13·8
+	262	51	313	16·3
	$\chi^2 = 1{\cdot}14$, df = 1, $P = 0{\cdot}285$			

+ indicates a history of birth complications, and − an absence.

Survey I consisted of a questionnaire returned by 936 undergraduates in which they were asked to report any known history of complications during birth, and also to complete a 28-item handedness questionnaire. Handedness was defined as in McManus (1979). Survey II consisted of a larger questionnaire, distributed on the eve of the graduation ceremony, to all graduands. The students, and also their parents, were asked to complete items relating to handedness, and the whole family was asked to report birth complications in the propositus and the siblings of the propositus. A total of 512 adequately completed questionnaires was received, and these replies contained information on a total of 1245 propositi and siblings. Information on birth complications in Survey II might be expected to be slightly more reliable (and perhaps to show a higher incidence of complications) than that in Survey I, since the mother in particular would have a more detailed recollection of the events of the birth. Nevertheless, given the work of Chamberlain & Johnstone (1975), which demonstrated the fallibility of mothers' memory for events of the previous parturition (only a few years previous), the present data should not be regarded as entirely convincing on the substantive issue.

Table 1 shows that in neither survey is there any evidence for a relationship between handedness and birth complications. Table 2 shows that, contrary to the findings of Bakan *et al.* (1973), there is no relationship, either in right- or left-handers, between a history of birth complications and a family history of sinistrality. In both

Table 2. *The relation between reported birth stress (or complications), and a family history (FH) of sinistrality, shown separately for Surveys I and II and for right- and left-handers*

		Survey I				Survey II			
		FH −	FH +	No.	%+	FH −	FH +	No.	%+
Right-handers									
Birth stress	−	463	55	518	10·6	349	131	480	27·3
	+	252	37	289	12·8	454	131	585	22·4
		$\chi^2 = 0{\cdot}67$, df = 1, $P = 0{\cdot}411$				$\chi^2 = 3{\cdot}41$, df = 1, $P = 0{\cdot}061$			
Left-handers									
Birth stress	−	25	2	27	7·4	30	17	47	36·2
	+	83	10	93	10·8	99	34	133	25·6
		$\chi^2 = 0{\cdot}02$, df = 1, $P = 0{\cdot}884$				$\chi^2 = 1{\cdot}93$, df = 1, $P = 0{\cdot}161$			

surveys, family history of propositi and siblings is defined in terms of the handedness of all the *remaining* family members, a single report of left-handedness being sufficient to define a positive family history.

There has been little other evidence to support the birth stress hypothesis, although this has not prevented it from being widely quoted as established truth. Bakan (1977) has pointed out that Barnes (1975), in a small prospective study ($N = 45$), found that the time taken for a newborn to achieve regular breathing after delivery correlated closely with subsequent handedness measured at the age of three. Barnes, however, puts a totally different interpretation upon this fact, suggesting 'that left-handed babies are more likely to have a stressful birth, rather than the stressful birth causing the left-handedness' (p. 202). Whether or not the hypothesis of Barnes deserves serious consideration will depend upon the same evidence which would test Bakan's hypothesis, for unless an effect is demonstrated both hypotheses must surely fail.

Bakan appears to have overlooked one small piece of evidence which could be construed as lending some support to his theory. Turkewitz *et al.* (1968) found that head turning in response to tactile stimulation (which normally shows a right-sided bias) was less asymmetric in a group of babies with low Apgar scores than in babies with high Apgar scores.

Bakan (1978) has cited experimental evidence by Brann & Myers (1975) that experimental asphyxia in neonatal rhesus monkeys affects only the left hemisphere if the hemispheres are affected asymmetrically; while superficially impressive, the study in fact refers to a total of 6 monkeys, of which only 3 had asymmetric softening, and the result is thus less than convincing in statistical terms.

As both Bakan (1977) and Hicks *et al.* (1978*a*) recognize, the only way of resolving these questions is by a prospective study. In this paper I report the results of such a study, about 12000 children being followed from birth to at least the age of 11 years. The children comprise a nationally representative sample from all social classes. Ironically, these data have been in existence for some years, and were available even before the start of the present controversy over birth-stress and left-handedness. Other aspects of handedness in these data have previously been considered by Calnan & Richardson (1976*a*, *b*).

METHOD

The data for the present study were those collected by the National Child Development Study (NCDS), and are now available to *bona fide* researchers via the Social Science Research Council's Archive of computer-readable data at the University of Essex. The NCDS study was originally the 1958 Perinatal Mortality Survey (PMS), which was sponsored by the National Birthday Trust Fund. It examined a wide range of obstetric factors relating to *all* children born in England, Wales, and Scotland during the period 3–9 March 1958. Obstetric and other data were collected by the midwife or doctor present at the birth, and are probably of a very high quality and accuracy. Extensive analyses of these data have already been published (Butler & Bonham, 1963; Butler & Alberman, 1969).

In 1964 the NCDS was set up in order to trace as many as possible of the children studied during the 1958 PMS. This study (NCDS I) looked at the children at about the age of 7, obtained interviews with parents and teachers, gave each child several ability tests, and also had each child examined by a doctor, Naturally it was not possible to obtain adequate answers on all items for all children, and some children were not subjected to a whole section of the survey (for example, the medical examination). Nevertheless, the response rate was extremely high. Many results from that study have already been reported (National Child Development Study, 1966, 1972).

A second study (NCDS II) was conducted in 1969, when the 1958 cohort was aged about 11. This study was esentially similar in content to that of NCDS I. A third study (NCDS III) was also carried out when the children were 16 years of age, but these data have not been used in the present study as they are not yet available for public re-analysis.

For the present study information was requested on some 500 variables on each of a total of 18285 children. This information was supplied on magnetic tapes which were analysed using the SPSS program package (Nie *et al.* 1975) on the IBM 370/165 computer at the University of Cambridge.

In view of the potential importance of the NCDS data for research on handedness, since the comprehensive nature of its information allows a whole range of studies, it is worthwhile in the present paper devoting a little space to an analysis of the formal structure of the handedness information. This analysis can be regarded as being complementary in some sense to another study of the structure of handedness (McManus, 1979), and provides further evidence that a simple classification of handedness into two categories, left and right, is adequate for most purposes.

THE STRUCTURE OF HANDEDNESS IN THE NCDS

The NCDS contains 5 variables explicitly concerned with hand *preference*. It also contains several items on differential skill of the 2 hands,

Table 3. *The 5 items in the NCDS data set which are concerned with hand preference*

NCDS item number	Age at assessment	NCDS survey	Person assessing child	Method of assessment	Item description in data manual	Possible responses
291	7	I	Mother (structured interview)	From memory	Laterality (hand) – mother's report	Right-handed Left-handed Mixed right and left
373	7	I	Doctor	Direct examination	Task: throw a crumpled paper ball Draw a cross	Only right hand used Only left hand used Both right and left hand used
1274	11	II	Mother (interview)	From memory	Ask mother if the child is . . .	Left-handed Right-handed Mixed right and left
1275	11	II	Mother (interview)	From memory	Which hand does your child write with?	Left hand Right hand
1582	11	II	Doctor	Direct examination	Ask child to throw ball to you. Did he/she use . . . ?	Right hand Left hand

Table 4. *The numbers of children, out of a total of* 11 029 *for whom adequate information was available on all* 5 *hand-preference items, who gave each particular combination of responses*

Item 1274	Item 291	Right Right	Right Left	Both Right	Both Left	Left Right	Left Left	<Item 373 <Item 1275 Item 1582
Right	Right	7849	1	852	0	31	0	Right
Right	Right	62	0	19	0	3	0	Left
Right	Mixed	338	1	63	1	0	0	Right
Right	Mixed	2	0	8	2	3	1	Left
Right	Left	31	0	12	0	2	0	Right
Right	Left	1	0	1	1	4	3	Left
Mixed	Right	223	3	27	4	2	1	Right
Mixed	Right	10	2	13	0	2	1	Left
Mixed	Mixed	131	6	31	16	1	2	Right
Mixed	Mixed	5	1	22	6	0	14	Left
Mixed	Left	0	4	5	27	1	8	Right
Mixed	Left	1	1	1	7	3	30	Left
Left	Right	13	7	3	7	0	0	Right
Left	Right	0	1	1	7	2	7	Left
Left	Mixed	3	7	2	25	0	9	Right
Left	Mixed	1	2	2	14	0	41	Left
Left	Left	1	21	0	136	0	68	Right
Left	Left	0	16	0	142	0	589	Left

Table 5. *The intercorrelation matrix for the 5 hand-preference items described in Table* 3

Item	1275	1274	291	1582	373
1275	—	0·917	0·861	0·744	0·766
1274	0·917	—	0·840	0·726	0·728
291	0·861	0·840	—	0·692	0·713
1582	0·744	0·726	0·692	—	0·701
373	0·766	0·728	0·713	0·701	—

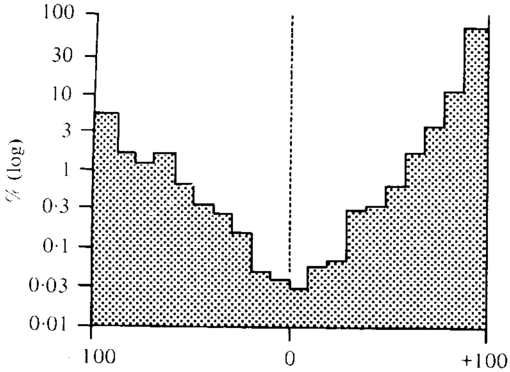

FIG. 1. The frequency distribution of individual scores on the first principal factor for 11029 subjects with information on all of the 5 handedness items. Note that the ordinate is logarithmic. The abscissa has been standardized so that the range is from + 100 to − 100.

and also questions on foot laterality and eye dominance; these items have been, or will be, considered elsewhere.

Table 3 summarizes the 5 items concerned with hand preference. Table 4 gives, for completeness, the number of children (out of a total of 11029 for whom valid information was available on all 5 hand-preference items) in each of the possible 108 response categories. Note that 25 (23·1 %) of the categories of Table 4 are actually empty, despite the large sample size. Table 5 shows an intercorrelation matrix for the 5 hand-preference items. All correlations are high, positive, and highly significant. Factor analysis of this 5 × 5 matrix gives eigenvalues of 4·08, 0·36, 0·29, 0·17 and 0·07, the first factor alone accounting for 81·7 % of the total variance. Clearly, this first factor is the only significant one. There is thus only a single dimension of handedness in the NCDS data. The question then arises as to the best way of dividing this continuum into categories, if at all. Estimated factor scores were calculated for each subject on the single dimension derived from the factor analysis, and

Table 6. *The relationship between the single variable derived from factor analysis, 'hand', and the individual items of which it is composed*

	Hand	
	Right	Left
Item 291		
Right	9113	40
Mixed	612	145
Left	63	1056
Item 373		
Right	8672	72
Both	1062	395
Left	54	774
Item 1274		
Right	9282	9
Mixed	478	133
Left	28	1099
Item 1275		
Right	9787	0
Left	1	1241
Item 1582		
Right	9622	356
Left	166	885

'Hand': see text for description and the 5 simple variables from which it is derived.

these factor scores were standardized so that the maximum and minimum possible scores were + 100 and − 100 (as in McManus, 1979). Fig. 1 shows the frequency distribution of individuals with particular factor scores. It may be noted that the ordinate of this figure is logarithmic, and thus the 'dip' in the centre is far steeper and deeper than it appears. From Fig. 1 it is clear that there are only two major categories present: right-handers having positive scores, and left-handers having negative scores. Using a criterion of zero on the standardized factor scores, the present population contains 11·25 % left-handers. While computationally correct, the criterion described is somewhat inconvenient. Table 6 shows the relation of handedness, as classified above, to each of the 5 variables of which the scale was initially constructed. The relation with item 1275, the writing hand of the child at the age of 11, is extremely close, only one child being misclassified if this variable is used instead of the above criterion derived from the factor analysis. In this and all future studies, therefore, 'handedness' will refer to the response recorded in item 1275. It is noteworthy that this conclusion is consistent with the arguments put forward elsewhere (McManus, 1979) that for the present data set the single best criterion of handedness is

Table 7. *The proportion of those children with and without the condition, who are left-handed, shown for those variables which can be regarded as dichotomous*

Condition	NCDS code number	Males: Condition absent No.	%L	Males: Condition present No.	%L	χ^2	Females: Condition absent No.	%L	Females: Condition present No.	%L	χ^2
Rhesus negative blood group	518	5050	12·8	941	13·6	0·352	4778	9·5	940	9·5	0·000
Abruptio placentae	522	6815	12·7	8	12·5	0·263	6483	9·5	8	12·5	0·097
Bleeding per vaginam prior to 28 weeks	522	6627	12·7	196	12·8	0·007	6273	9·4	218	11·9	1·299
Placenta praevia	522	6805	12·7	18	27·8	2·458	6454	9·5	37	13·5	0·313
Other bleeding in pregnancy	522	6696	12·7	127	15·0	0·403	6354	9·4	137	10·9	0·200
Caesarean section	534	6637	12·6	186	16·1	1·713	6344	9·4	147	14·3	3·505
Forceps	534	6494	12·7	329	12·8	0·002	6253	9·5	238	10·1	0·045
Breech presentation	534	6741	12·7	82	14·6	0·129	6370	9·5	121	9·1	0·000
Occipito–posterior presentation	534	6678	12·7	145	11·7	0·054	6335	9·5	156	9·0	0·006
Other abnormality of presentation (face, shoulders, etc.)	534	6803	12·7	20	15·0	0·001	6468	9·4	23	26·1	5·610
Umbilical cord prolapse	535	6488	12·8	8	12·5	0·251	6164	9·5	9	11·1	0·160
Meconium staining of amniotic fluid	535	6388	12·8	108	13·9	0·035	6087	9·4	86	12·8	0·769
Foetal heart distress	535	6306	12·8	190	12·6	0·001	6048	9·4	125	11·2	0·267
Other signs of foetal distress	535	6134	12·8	362	13·3	0·031	5870	9·4	303	11·2	0·947
Rhesus incompatibility	1831	6800	12·7	23	13·0	0·070	6451	9·4	40	15·0	0·857
Neonatal hyperbilirubinaemia	1831	6814	12·7	9	22·2	0·127	6482	9·5	9	0·0	0·161
Neonatal convulsions or cyanosis	1831	6782	12·7	41	19·5	1·160	6473	9·4	18	22·2	2·091
Neonatal hypothermia	1831	6816	12·7	7	14·3	0·195	6487	9·5	4	25·0	0·042
Respiratory distress	1831	6813	12·7	10	0·0	0·536	6482	9·5	9	11·1	0·161
Pyloric stenosis	1831	6803	12·7	20	5·0	0·490	6480	9·5	11	0·0	0·312
Other miscellaneous neonatal problems	1831	6782	12·8	41	4·9	1·624	6454	9·5	37	13·5	0·313
Maternal diabetes	1837	6817	12·7	6	16·7	0·103	6484	9·5	7	14·3	0·044
Maternal heart disease	1837	6769	12·7	54	11·1	0·022	6440	9·5	51	3·9	1·253
Hydramnios	1837	6807	12·7	16	12·5	0·123	6475	9·5	16	12·5	0·000
Maternal tuberculosis	1837	6812	12·7	11	9·1	0·008	6470	9·5	21	14·3	0·145
History of previous toxaemia	509	6076	12·7	418	14·8	1·420	5802	9·5	368	9·5	0·003
History of previous antepartum haemorrhage	509	6346	12·8	148	12·8	0·014	6038	9·4	132	11·4	0·363
History of previous Caesarean section	509	6413	12·8	81	13·6	0·001	6103	9·5	67	6·0	0·597

χ^2 values use Yates' correction for continuity.

the writing hand. It is, of course, a theoretical possibility that birth stress primarily affects *degree* of handedness rather than direction of handedness: I have found no evidence for this position in a separate study (McManus, 1979).

HANDEDNESS AND BIRTH STRESS

The NCDS data contain a large amount of information on the pre-natal and perinatal condition of each child, the information being collected at the time of birth, and therefore having a high degree of accuracy. In all the following tables, children have been considered only if they are singletons without congenital defects.

Table 7 shows the relation between left-handedness and the occurrence of each of 28 dichotomous items which might be predicted to increase, or to be associated with, birth stress. Results are given for all singleton births without congenital defects, male and female births being considered separately. In the NCDS data set there is a significantly higher incidence of left-handedness in male children (12·81 %) than in female children (9·64 %), and therefore data combined by sex might sometimes give spuriously significant results, particularly if a complication were itself of different incidence in the two sexes, as is known to be the case for some aspects of perinatal mortality and morbidity (Butler & Bonham, 1963; Butler & Alberman, 1969).

Table 8. *The proportion of each class which are left-handed, shown for those variables which have 3 or more categories*

Condition	NCDS code number	Group	Males No.	Males %L	Males χ^2 test	Males K–S test	Females No.	Females %L	Females χ^2 test	Females K–S test
Social class	492	I	272	12·9	χ^2 = 2·07	z = 0·437	248	9·7	χ^2 = 2·61	z = 0·439
		II	824	11·5	df = 4	NS	789	8·0	df = 4	NS
		III	3737	13·0	P = 0·721		3544	9·7	P = 0·623	
		IV	755	13·6			744	8·9		
		V	607	13·7			536	9·1		
Parity	504	0	2336	12·4	χ^2 = 5·38	z = 0·356	2289	9·8	χ^2 = 4·08	z = 0·610
		1	2105	13·2	df = 6	NS	1886	9·8	df = 6	NS
		2	1002	13·9	P = 0·496		973	8·5	P = 0·664	
		3	509	11·8			480	7·9		
		4	241	10·0			238	10·9		
		5	127	16·5			153	7·8		
		6+	175	12·6			154	10·4		
Previous abortions, or ectopic pregnancies	505	0	5740	12·9	χ^2 = 3·06	z = 0·215	5450	9·5	χ^2 = 0·18	z = 0·104
		1	616	13·0	df = 2	NS	582	9·3	df = 2	NS
		2	103	7·8	P = 0·215		110	8·2	P = 0·912	
		3+	36	8·3			31	9·6		
Previous premature livebirths	506	0	5938	12·7	χ^2 = 0·09	z = 0·083	5629	9·3	χ^2 = 2·25	z = 0·323
		1	415	13·3	df = 2	NS	406	9·9	df = 2	NS
		2	76	11·8	P = 0·951		69	11·6	P = 0·323	
		3+	24	16·6			25	22·2		
Previous stillbirths	508	0	6147	12·9	χ^2 = 1·40	z = 0·242	5845	9·5	χ^2 = 5·57	z = 0·150
		1	311	11·3	df = 2	NS	300	8·3	df = 2	NS
		2+	36	8·3	P = 0·496		27	22·2	P = 0·061	
Mother's minimum haemoglobin level (g/100 ml)	519	10·5	3595	12·3	χ^2 = 0·76	z = 0·683	3402	9·5	χ^2 = 3·55	z = 0·266
		9·0–10·4	495	13·3	df = 2	NS	467	10·5	df = 2	NS
		<9·0	113	10·6	P = 0·683		94	4·3	P = 0·169	
Length of first stage of labour (hours)	527	<3	600	14·8	χ^2 = 7·93	z = 0·474	565	8·3	χ^2 = 7·77	z = 0·733
		3–6	1458	12·7	df = 6	NS	1325	10·3	df = 6	NS
		6–12	2128	12·6	P = 0·242		2095	8·4	P = 0·255	
		12–24	1498	12·4			1439	10·1		
		24–48	472	10·8			433	10·6		
		48–72	72	18·1			48	10·4		
		>72	22	22·7			17	17·6		
Length of second stage of labour (minutes)	528	<30	2977	13·9	χ^2 = 12·93	z = 1·376	2982	9·7	χ^2 = 4·51	z = 0·445
		30–60	1720	11·6	df = 8	P = 0·045	1601	9·2	df = 8	NS
		60–90	736	11·8	P = 0·114		669	8·2	P = 0·989	
		90–120	338	10·4			266	9·4		
		120–150	189	12·7			159	10·7		
		150–180	75	13·3			70	7·1		
		180–210	45	4·4			31	16·1		
		210–240	21	4·8			15	6·7		
		>240	32	18·8			20	5·0		

Table 8. (*cont.*)

Duration of membrane rupture (hours)	529	<3	3860	13·4	χ^2 = 14·26	z = 1·137	3852	9·4	χ^2 = 3·44	z = 0·174
		3–6	603	10·6	df = 8	NS	484	9·9	df = 8	NS
		6–12	565	11·3	P = 0·075		471	8·7	P = 0·903	
		12–24	462	10·0			428	8·9		
		24–48	303	10·9			281	10·0		
		48–72	105	16·2			93	11·8		
		72–120	73	12·3			66	12·0		
		120–168	23	21·7			12	0·0		
		<168	21	23·8			18	5·6		
Inhalational anaesthesia	536	Not available	223	11·7	χ^2 = 5·08		231	8·2	χ^2 = 5·09	
		Gas and air	3548	12·9	df = 8		3357	8·9	df = 8	
		Trilene	1461	12·0	P = 0·748		1389	10·0	P = 0·747	
		Gas, air and trilene	136	14·0			152	11·2		
		Gas and oxygen	14	7·1			14	7·1		
		Not indicated	537	15·1			497	10·9		
		Contra-indicated	169	11·8			152	10·5		
		No time	160	15·0			166	11·4		
		Refused	227	11·9			205	10·2		
Surgical induction	531	None	6054	12·7	χ^2 = 0·820		5785	9·6	χ^2 = 3·04	
		Low	276	13·0	df = 4		262	8·0	df = 4	
		High	150	14·7	P = 0·935		132	9·8	P = 0·550	
		Yes, type NK	207	11·6			202	6·4		
		OBE, oestrogen or strip	136	13·2			110	10·0		
Oxytocin induction	531	None	6483	12·7	χ^2 = 0·30		6186	9·6	χ^2 = 0·97	
		Yes	307	13·4	df = 2		291	7·9	df = 2	
		Only in labour	33	15·2	P = 0·858		14	7·1	P = 0·615	
Toxaemia	548	None	4833	13·1	χ^2 = 3·02	z = 0·759	4711	9·5	χ^2 = 7·84	z = 0·282
		Mild	1154	11·4	df = 4	NS	1079	8·8	df = 4	NS
		Moderate	280	12·1	P = 0·554		254	9·4	P = 0·0973	
		Severe	259	12·0			222	14·4		
		Proteinuria (? cause)	297	12·1			225	7·6		
Smoking after 4th month of pregnancy	639	None	4285	12·7	χ^2 = 1·27	z = 0·245	4082	9·2	χ^2 = 1·25	z = 0·344
		Medium	983	13·9	df = 3	NS	955	10·4	df = 3	NS
		Heavy	754	12·3	P = 0·734		711	9·1	P = 0·739	
		Variable	395	12·9			351	9·7		
Number of antenatal problems (ARFC)		0	3785	12·4	χ^2 = 1·19	z = 0·090	3509	9·4	χ^2 = 1·48	z = 0·165
		1	385	11·7	df = 2	NS	403	10·7	df = 2	NS
		2	33	19·4	P = 0·550		48	6·3	P = 0·477	
		3	2	0·0			3	0·0		
Number of intrapartum problems (IRFC)		0	5023	12·8	χ^2 = 1·17	z = 0·296	4823	9·4	χ^2 = 1·69	z = 0·245
		1	654	11·9	df = 5	NS	659	9·1	df = 5	NS
		2	630	13·8	P = 0·947		560	10·5	P = 0·889	
		3	138	13·8			90	8·9		
		4	44	13·6			35	11·4		
		5	7	14·3			6	0·0		
Number of neonatal problems (NRFC)		0	6680	12·7	χ^2 = 0·316	z = 0·079	6371	9·4	χ^2 = 2·12	z = 0·196
		1	135	11·1	df = 2	NS	112	13·4	df = 2	NS
		2	8	12·5	P = 0·853		8	12·5	P = 0·344	

χ^2 values are given for all items; Kolmogorov–Smirnov two-sample tests are reported for items which can be regarded as ordinal in structure.

Table 9. *The mean, standard deviation, and sample number for left- and right-handers for those variables which are continuous in their distribution*

Variable	NCDS code number	Males				Females			
		Right-handers*	Left-handers	*F*-test	K–S test	Right-handers	Left-handers	*F*-test	K–S test
Father's age	494	30·53 ± 6·49 (5484)	30·14 ± 6·21 (811)	$F(1,6293) = 2·55$, $P = 0·110$	$z = 0·903$ NS	30·63 ± 6·32 (5381)	30·75 ± 6·78 (555)	$F(1,5934) = 0·186$, $P = 0·665$	$z = 0·578$ NS
Mother's age	553	27·47 ± 5·70 (5661)	27·16 ± 5·34 (832)	$F(1,6491) = 2·11$, $P = 0·146$	$z = 0·822$ NS	27·50 ± 5·67 (5587)	27·41 ± 6·01 (583)	$F(1,6168) = 0·143$, $P = 0·705$	$z = 0·894$ NS
Mother's height (in)	510	63·39 ± 2·50	63·43 ± 2·52	$F(1,6244) = 0·16$, $P = 0·687$	$z = 0·293$ NS	63·42 ± 2·50	63·40 ± 2·47	$F(1,5939) = 0·039$, $P = 0·843$	$z = 0·363$ NS
Mother's weight (stones)	496	8·87 ± 1·50 (5529)	8·84 ± 1·46 (811)	$F(1,6338) = 0·291$, $P = 0·589$	$z = 0·032$ NS	8·85 ± 1·48 (5460)	8·84 ± 1·57 (572)	$F(1,6030) = 0·020$, $P = 0·88$	$z = 0·606$ NS
Gestation period (days)	497	280·9 ± 11·81 (5123)	280·4 ± 11·99 (744)	$F(1,5865) = 1·15$, $P = 0·639$	$z = 0·743$ NS	281·6 ± 11·92 (4999)	281·2 ± 12·39 (515)	$F(1,5512) = 0·625$, $P = 0·793$	$z = 0·649$ NS
Birth weight (oz)	646	120·8 ± 18·42 (5467)	119·5 ± 22·45 (794)	$F(1,6259) = 3·57$, $P = 0·058$	$z = 1·433$, $P = 0·033$	115·9 ± 17·45 (5418)	115·1 ± 18·22 (572)	$F(1,5988) = 1·283$, $P = 0·699$	$z = 0·699$ NS
Perinatal mortality predictor scale		−476·4 ± 208·6 (5385)	−478·1 ± 196·0 (798)	$F(1,6181) = 0·047$, $P = 0·828$	$z = 0·740$ NS	−479·8 ± 203·4 (5308)	−463·3 ± 225·9 (545)	$F(1,5851) = 3·205$, $P = 0·073$	$z = 0·977$ NS

F-values are given for a one-way analysis of variance and, in view of possible non-normalities being confounded by the large sample size, a Kolmogorov–Smirnov two-sample test is also reported.

* The values shown are mean ± S.D. with the number of subjects in parentheses.

Yates' correction has been applied to the two-tailed chi-squared tests reported in Table 7.

The great majority of the differences in Table 7 fail to reach significance, thus arguing against a relation between handedness and birth trauma. However, it might be argued that many of the variables shown in Table 7 actually show a small correlation with handedness and that this correlation is in the expected direction. Thus the combined impact of all of these minor correlations might be to produce an overall correlation which is significant. To assess this possibility the exact probability values for each 2 × 2 matrix were calculated, and these two-tailed probabilities converted to one-tailed probabilities (by taking into account the direction of the result found); these one-tailed probabilities were then combined, using the method of Kendall (1951). Even when this has been carried out, the results shown in Table 7 still show no significant relation between left-handedness and birth stress, either for males ($\chi^2 = 53{\cdot}31$, df = 56, $P = 0{\cdot}577$), or for females ($\chi^2 = 71{\cdot}13$, df = 56, $P = 0{\cdot}083$). Note that in the present data it is in the *females* in whom the greater effect is found, contrary to the findings of Bakan, who suggests that males are more likely to show such a link between handedness and birth stress.

Examination of the chi-squared values in Table 7 shows that only one item is significant at the 0·05 level: there is an increased incidence of left-handers in those having 'other abnormalities of presentation' in females only ($P = 0{\cdot}018$). However, this result is not significant in males ($P = 0{\cdot}97$). In view of the multiple significance testing that has been carried out, this single significant result may be best regarded as a Type I error.

Table 8 shows similar results to Table 7 for those variables with more than two possible response categories. Chi-squared values for homogeneity are given for all variables. For those variables which are ordinal in their classification a Kolmogorov–Smirnov two-sample test was also carried out to check for differences in overall distribution between the left-handed and the right-handed children.

The significance values of Table 8 may also be combined by addition of the chi-squared values. This has been carried out for the first 14 items (i.e. 'social class' to 'smoking', inclusive) and gives values of $\chi^2 = 57{\cdot}03$, df = 61, for males and $\chi^2 = 52{\cdot}22$, df = 61, for females; neither value is statistically different from chance expectations.

Table 9 shows the breakdown of those variables which were cardinal and for which there were a sufficiently large number of possible responses to allow the use of statistics designed for continuous distributions. F-tests of significance have been carried out for all these items; in addition, the Kolmogorov–Smirnov two-sample test is also reported in view of the possibility of small degrees of non-normality being confounded by the large sample size to produce spuriously significant or non-significant results.

Several composite indices of the data presented in Tables 7, 8 and 9 have also been produced. Goldstein (1969) has used the variables age, parity, social class, height, smoking and pre-eclampsia to predict the perinatal mortality rate. All are independent predictors of differing strengths and, after their combined use (with appropriate weighting), a non-significant degree of variance is left unaccounted. Table 9 shows my own reconstruction of this variable (called the perinatal mortality predictor scale (PMPS)), in left- and right-handers. There is no significant difference between the two groups when a non-parametric test is used (the distribution being strongly non-normal: skewness = 1·22, kurtosis = 1·12).

Three other indices have also been constructed, these being simple counts of adverse events occurring during a particular period. The antenatal risk factor count (ARFC) was a simple count of the following variables:

maternal haemoglobin of less than 9 g/100 ml
placenta praevia with bleeding
abruptio placenta with bleeding
any vaginal bleeding before 28 weeks
any other vaginal bleeding after 28 weeks
maternal diabetes
maternal heart disease
maternal TB (active)
hydramnios.

It may be noted that none of these items overlaps with the items in the PMPS.

The intrapartum risk factor count (IRFC) was a simple count of the number of events from the following list:

Caesarean section

use of forceps during delivery
breech presentation
occipito–posterior presentation
other abnormality of presentation (face, shoulders, etc.)
umbilical cord prolapse
meconium staining of amniotic fluid
foetal distress as indicated by abnormality of foetal heart rate
other signs of foetal distress.

The neonatal risk factor count (NRFC) was a simple count of all adverse events recorded after delivery of the child, i.e.

rhesus incompatibility
hyperbilirubinaemia
neonatal convulsions or cyanosis
neonatal hypothermia
respiratory distress
pyloric stenosis
other miscellaneous neonatal conditions.

A composite risk factor count (CRFC) was also constructed by using all the variables already described for the ARFC, IRFC and NRFC, and also adding to this list dichotomized versions of the variables used in the PMPS, as well as several others which might be thought pertinent to the question of birth stress and handedness. The extra variables were:

mother's weight greater than 10 stones 13 pounds
mother's height less than 62 inches
gestation period less than 36 weeks or greater than 42 weeks
parity zero or greater than 2
history of previous spontaneous abortions or ectopic pregnancies
history of previous premature livebirths
history of previous stillbirths or neonatal deaths
history of previous toxaemia
history of previous antepartum haemorrhage
history of previous Caesarean section
first stage of labour longer than 24 hours
second stage of labour longer than 2 hours
membrane rupture longer than 48 hours
mother's age greater than 29 years
mother smoked after 4th month of pregnancy
surgical induction of labour carried out
oxytocin usage during labour

Table 10. *The number of adverse events reported during pregnancy and the neonatal period for males and females separately*

No. adverse events	Males No.	Males %L	Females No.	Females %L
0	764	13·6	733	7·9
1	1272	13·1	1256	9·7
2	1235	11·5	1156	9·5
3	956	13·1	852	10·6
4	678	11·5	633	9·3
5	413	14·5	385	8·6
6	258	9·3	230	9·1
7	144	15·3	143	10·5
8	86	19·8	73	4·1
9	45	17·8	39	17·9
10	24	8·3	27	18·5
11	10	0·0	5	0·0
12	4	0·0	1	0·0
13	1	0·0	1	0·0
Right (mean ± S.D.)	2·622 ± 2·068		2·567 ± 2·052	
Left (mean ± S.D.)	2·624 ± 2·112		2·640 ± 2·073	
χ^2	12·98		15·62	
df	13		13	
P	0·449		0·269	
K–S *z*	0·518		0·448	
P	NS		NS	

The results of a χ^2 test for homogeneity and of a Kolmogorov–Smirnov two-sample test are reported; non-parametric tests are used in view of the clear non-linearity of the data.

moderate or severe toxaemia (as defined by Butler & Bonham, 1963).

The number of items on each of the scales ARFC, IRFC, NRFC and CRFC was 9, 9, 7 and 43 respectively. Clearly it is not possible to attain these maximum scores since some of the items are mutually exclusive. Results for the ARFC, IRFC and NRFC have already been presented in Table 8; none shows a significant relation with handedness. Table 10 shows the distribution of scores for males and females on the composite risk factor score. For none of the groups is there a significant difference between right- and left-handers; this is also reflected in the absence of a difference in means of right- and left-handers.

CONCLUSIONS

In this paper I have reported results from two moderately large retrospective studies, and one very large prospective study of the relation between birth complications and subsequent left-handedness. None of the studies produced any substantial evidence for a relation between birth stress and left-handedness.

There seems little doubt that birth stress is unlikely to play any role in the development of left-handedness in the majority of the population. It may be concluded safely that the incidence of left-handedness need be of no concern to obstetricians anxious to monitor the efficiency of their services.

I am grateful to the National Children's Bureau for so readily allowing me to study their data, and also to Mr E. Roughley for his assistance in retrieving the data from the SSRC's Survey Archives. I wish to thank Professor M. J. Morgan for critically reading the manuscript.

Survey II could not have taken place without the assistance of Ms Diana Lockwood.

REFERENCES

Bakan, P. (1971). Handedness and birth order. *Nature (London)* **229**, 195.

Bakan, P. (1975). Are left-handers brain damaged? *New Scientist* **67**, 200–202.

Bakan, P. (1977). Left-handedness and birth order revisited. *Neuropsychologia* **15**, 837–839.

Bakan, P. (1978). Why left-handedness? *Behavioural and Brain Sciences* **1**, 279–280.

Bakan, P., Dibb, G. & Reed, P. (1973). Handedness and birth stress. *Neuropsychologia* **11**, 363–366.

Bakketeig, L. S. & Hoffman, H. J. (1979). Perinatal mortality by birth order within cohorts based on sibship size. *British Medical Journal* ii, 693–696.

Barnes, F. (1975). Temperament, adaptability, and left-handers. *New Scientist* **67**, 202–203.

Brann, A. W. & Myers, R. E. (1975). Central nervous system findings in the newborn monkey following severe *in utero* partial asphyxia. *Neurology* **25**, 327–338.

Butler, N. R. & Alberman, E. D. (eds.) (1969). *Perinatal Problems*. Livingstone: Edinburgh.

Butler, N. R. & Bonham, D. G. (1963). *Perinatal Mortality*. Livingstone: Edinburgh.

Calnan, M. & Richardson, K. (1976*a*). Developmental correlates of handedness in a national sample of 11-year-olds. *Annals of Human Biology* **3**, 329–342.

Calnan, M. & Richardson, K. (1976*b*). Speech problems among children in a national survey: associations with hearing, handedness and therapy. *Community Health* **8**, 101–106.

Chamberlain, G. & Johnstone, F. D. (1975). Reliability of the history. *Lancet* i, 103.

Goldstein, H. (1969). The effect of maternal age, parity, social class, height, degree or pre-eclampsia and smoking in pregnancy, on still-birth plus neonatal mortality rates. In *Perinatal Problems* (ed. N. R. Butler and E. D. Alberman), pp. 45–46. Livingstone: Edinburgh.

Hicks, R. A., Pellegrini, R. J. & Evans, E. A. (1978*a*). Handedness and birth risk. *Neuropsychologia* **16**, 243–245.

Hicks, R. A., Evans, E. A. & Pellegrini, R. J. (1978*b*). Correlation between handedness and birth order: compilation of five studies. *Perceptual and Motor Skills* **46**, 53–54.

Hubbard, J. I. (1971). Handedness is not a function of birth order. *Nature (London)* **232**, 276–277.

Kendall, M. G. (1951). *The Advanced Theory of Statistics* (third edn) Vol. 2, pp. 132–133. C. Griffin: London.

Leviton, A. & Kilty, T. (1976). Birth order and left-handedness. *Archives of Neurology* **33**, 664.

McManus, I. C. (1979). Determinants of laterality in man. Ph.D. thesis: University of Cambridge.

National Child Development Study (1966). 11 000 *Seven-Year-Olds*. Longmans: London.

National Child Development Study (1972). *From Birth to Seven*. Longmans: London.

Nie, N. H., Hull, C. H., Jenkins, J. G., Steinbrenner, K. & Bent, D. H. (1975). *SPSS: Statistical Package for the Social Sciences*. McGraw-Hill: New York.

Schwartz, M. (1977). Left-handedness and high-risk pregnancy. *Neuropsychologia* **15**, 341–344.

Turkewitz, G., Moreau, T. & Birch, H. G. (1968). Relation between birth condition and neuro-behavioural organisation in the neonate. *Pediatric Research* **2**, 243–249.