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Handedness, footedness, eyedness and earedness in the Colorado Adoption Project

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Dominance of hand, foot, ear and eye was examined in the Colorado Adoption Project (CAP) to examine whether previously reported familial trends in lateralization are the result of genetic or environmental processes. Despite a relatively large sample size for an adoption study, and evidence that the measures of lateralization were typical of those found in other studies, no significant familial trends were found in any of the measures of direction of lateralization. Nevertheless, effects found for handedness were of a similar magnitude to that shown elsewhere in the literature and it was concluded that this adoption study alone did not have sufficient statistical power to partition variance into genetic and environmental components. Other studies taken alone are also likely to suffer from the same problem, and therefore the question is only likely to be definitively resolved by combining data from a number of studies by means of meta-analysis.

Degree of lateralization was also examined and no evidence was found for familial trends in handedness, footedness, eyedness or earedness. Power analysis suggested that the present data were sufficient to detect effects similar to those previously reported for handedness and that this result was best interpreted as a true failure of replication of familial association for handedness. The study is also the first to examine degree of eyedness, earedness and footedness, and finds no evidence for familial associations.

As a population, humans show lateralization, about 90 per cent of adults being right-handed, about 80 per cent being right-footed, about 70 per cent being right-eyed, and about 60 per cent being right-eared by preference (Porac & Coren, 1981). Hand preference has been shown in many studies to run in families, the offspring of two left-handed parents being more likely to be left-handed than the offspring of two right-handed parents, as has been reviewed elsewhere (Annett, 1985; McManus & Bryden, 1992). Similarly, there are data in the literature suggesting that eyedness runs in families (Zoccolotti, 1978), and that footedness shows familial trends (Porac & Coren, 1981).

Hand preference is the most studied form of lateralization. Combined data from the many studies suggests that familial trends in handedness do indeed exist, and these have

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typically been explained by genetic models, the most successful being those of Annett (1985), and McManus (1985, 1991; McManus & Bryden, 1992). Both models argue that lateralization is a genetic process coupled with a random factor, or 'fluctuating asymmetry', which can be conceptualized as an environmental influence. A potential weak link is that although *familial* trends are undoubtedly present, such trends may result from environmental rather than *genetic* factors. Adoption studies are the most convincing method for demonstrating that familial trends indeed result from genetic factors. In the case of handedness, few studies have looked at adopted children, and none are entirely adequate methodologically. The study of Carter-Saltzmann (1981) is the best, although child handedness was only assessed in relation to adoptive parents and not to the handedness of biological parents; the control group was therefore either the biological children of the adoptive parents, or randomly chosen (biological) families. A group of 408 young adults adopted in infancy was compared with 400 non-adopted controls; however these children came from 205 biological and 286 adoptive families, there sometimes being several children in a family, a factor not taken into account in the statistical analysis, thereby probably inflating the significance levels. Handedness of controls was significantly related to that of their biological parents, whereas no association was found between the handedness of adopted children and adoptive parents; however the group by handedness interaction was not tested for significance in the original study, and it was not significant when we calculated it. The study also classified individuals as right vs. non-right, a measure which partially confounds direction and degree of handedness. The study of Rice, Plomin & De Fries (1984) was a part of the Colorado Adoption Project (CAP), and examined the handedness of 152 adopted and 120 control children aged 12 and 24 months in relation to the handedness of biological and adoptive parents. Parent–offspring correlations were generally weak, and 'did not conform to that [pattern] expected on the basis of either genetic or family environmental influences' (p. 688). However, although methodologically sound, the study assessed handedness at an early age when it is far from completely fixed (Butterworth & Hopkins, 1993; Durost, 1935; Gesell & Ames, 1947; Liederman, 1983; McManus, Sik, Cole, Mellon, Wong & Eloss, 1988; Michel, 1983). The final two studies using an adoption paradigm are those of Hicks & Kinsbourne (1976) and Longstreth (1980). Both were 'partial cross-fostering' designs, studying children who, as a result of parental divorce, were raised by non-biological parents. However, the average age of cross-fostering was 7.55 years in Longstreth's study, and 12.94 years in Hicks & Kinsbourne's study, by which time direction of handedness is generally regarded as fixed in most individuals, and hence adoptive parents could have had little influence.

In the present study, we describe lateralization in children at the age of 7 in the Colorado Adoption Project in relation to laterality of biological, adoptive, and control parents, considering not only handedness, but also footedness, eyedness, and earedness; and assessing separately the effects of direction of lateralization and degree of lateralization on each measure.

Method

The CAP, in which data collection began in 1975, has been described extensively elsewhere (DeFries, Plomin & Fulker, 1994; Plomin & DeFries, 1985). Briefly, this longitudinal full adoption study includes a large number of children who were adopted in early infancy (average age at adoption = 29 days), their adoptive and biological parents, and a matched control group of non-adoptive parents and children. More

recently, adoptive and non-adoptive siblings have been added to the sample (Plomin, DeFries & Fulker, 1988). Adoptive and control children were tested at 1 year of age, and afterwards at intervals of about one year. The majority of biological mothers and approximately 20 per cent of biological fathers were tested before adoption (i.e. during pregnancy). Adoptive parents were tested after adoption, and control parents were tested after the birth of their child. Additional data on adoptive and control parents has been collected throughout the study.

The handedness of biological, adoptive and control parents was measured as part of a three-hour battery of tests and questionnaires administered during the initial assessment. Parents completed a 10-item questionnaire on handedness, indicating the hand used for writing, eating, throwing, cutting with scissors, holding a match, holding a tennis racquet, threading a needle, brushing teeth, hammering a nail, and opening a jar. On each item there was a three-point scale of left, mixed and right, scored as -1, 0 and $+1$.

When the child was 7 years of age, handedness of the child and his/her adoptive and/or control parents was assessed using an 18-item laterality inventory. For children, the questions were read by an examiner and the child was asked to act out each item using the appropriate instrument. Adoptive and control parents indicated their laterality on the same items, but were not required to act out the behaviours. *Handedness* (HAND) was assessed by means of nine items (hand used for drawing, throwing a ball, using an eraser, dealing a card, eating, holding scissors, lighting a match, brushing teeth, and hammering a nail). *Footedness* (FOOT) was assessed by three items (kicking a ball, picking up a pebble, stepping onto a chair), *Eyedness* (EYE) was assessed by three items (looking through a keyhole, looking into a bottle, and looking through a telescope), and *Earedness* (EAR) was also assessed by three items (listening at a door, listening to a heart beat, and using an earphone). Items were scored on a three-point scale of left, mixed and right, scored as -1, 0 and $+1$. For a number of practical reasons, missing data were present for all measures, and in particular some individuals were not tested on eyedness, footedness and earedness, resulting in the different *N*s in the tables.

Laterality data for biological parents includes only the handedness data collected at the beginning of the study. Therefore, in the present analyses, parent data on handedness comes from the initial laterality questionnaire which is similar, although not quite identical, to the inventory administered when the children were 7 years of age. As with the offspring data, some measures are missing for some parents.

A laterality index (LI) in the range -100 to $+100$ was calculated separately for HAND, FOOT, EYE and EAR, computed as $100.\sum(I_i)/n$, where I_i is the ith of n items on that scale. Direction of lateralization was scored as left for LI ≤ 0 and right for LI > 0, and degree of lateralization was scored as the absolute value of LI (that is, ignoring the sign, so that values are in the range 0 to 100). In addition handedness was also classified by the hand used for writing (WRITE), and this is indicated separately in the tables. It should be noted that not all participants had full information on both HAND and WRITE.

Because of missing data, there are some minor discrepancies in the total numbers of participants in the tables which are based on all cases for whom appropriate data were available.

Results

Direction of lateralization

Table 1 shows the proportions of parents and children who are left-lateralized on HAND, WRITE, FOOT, EAR and EYE. Proportions are similar to those reported in the large study of Porac & Coren (1981). It should be noted that HAND and WRITE are very similar, 93.44 per cent of individuals with a laterality index less than or equal to zero write with the left hand, and 97.76 per cent of individuals with a laterality index greater than zero write with the right hand. The sex differences in handedness, although not significant, are of a similar size to the 27.4 per cent difference found in the meta-analysis carried out by Seddon & McManus (McManus, 1991), males having an incidence 26.01 per cent higher than that in females (i.e. the incidence of left-handedness in the males (10.03 per cent) is 26 per cent larger than the incidence in the females (7.96 per cent) calculated as $100\times(10.03-7.96)/7.96$). The sex difference in the incidence of footedness

Table 1. The incidence of left-handedness, footedness, eyedness and earedness in the various groups. Figures in parentheses in the final row show, for comparative purposes, the data of Porac & Coren (1981) in their sample of 5147 individuals, most of whom were in the age range 16–25

	N (HAND)	% L HAND (LI ≤ 0)	*N* (WRITE)	% L (WRITE)	*N* (FOOT, EYE, EAR)	% L FOOT	% L EYE	% L EAR
Control children—male	114	13.16**	114	11.40*	109	27.52	33.94	33.03
Control children—female	99	2.02**	99	2.02*	93	19.35	31.18	31.18
Control mothers	213	9.86	206	11.65	202	12.38	31.68	30.69**
Control fathers	211	9.95	206	10.68	188	17.55	29.79	50.00**
Adopted children—male	113	7.96	113	7.96	107	30.84	31.78	24.30
Adopted children—female	103	10.68	103	9.71	99	25.25	26.26	27.27
Adoptive mothers	211	6.64	196	8.16	206	7.28	27.18	29.13**
Adoptive fathers	207	8.70	188	9.04	178	12.92	23.03	46.07**
Biological mothers	216	8.80	169	11.24	—	—	—	—
Biological fathers	43	13.95	34	11.76	—	—	—	—
Total—males	688	10.03	655	9.92	582	20.45**	28.87	40.89***
Total—females	842	7.96	773	9.18	600	13.83**	29.17	29.67***
Total—all participants (Porac & Coren data)	1530	8.89 (11.8)	1428	9.52	1182	17.09 (19.0)	29.02 (28.9)	35.19 (40.6)

Significant sex differences within groups are indicated by: *$p < .05$; **$p < .01$; ***$p < .001$.

Table 2. Associations (phi coefficients) between laterality measures; parents (adoptive and control, $N = 774$) above diagonal, children (adoptive and control, $N = 408$) below diagonal. Figures in brackets indicate, for comparative purposes, the correlations found by Porac & Coren (1981) in their sample of 5147 individuals, most of whom were in the age range 16–25

	HAND	FOOT	EYE	EAR
HAND	–	.238*** (.527)	.250*** (.310)	.268*** (.247)
FOOT	.446***	–	.112* (.264)	.238*** (.354)
EYE	.295***	.175***	–	.194*** (.216)
EAR	.158***	.218***	.192***	–

Significant associations are indicated by: *$p < .05$; **$p < .01$; ***$p < .001$.

is also similar to that of Porac & Coren (1981). Table 2 shows the interrelations between HAND, EYE, FOOT and EAR, as described by phi coefficients. Detailed analysis is not necessary, save to state that the figures are compatible with those reported in the large study of Porac & Coren (1981). Tables 1 and 2 therefore confirm the overall validity and typicality of the data, and of the methods of measurement.

The important issue concerns the relation between laterality of control children and parents, and laterality of adopted children and adoptive and biological parents (Table 3). Overall, there are few significant associations between parental and offspring handedness, either in the adopted children or in the control children.

Table 3. Laterality of children (*N*, %Left) in relation to the laterality of parents, for control children, and for adopted children in relation to adoptive and biological parents. Because of the small number of biological fathers of adopted children for whom there were data, laterality for biological parents is only shown in relation to the mother. (R×L: Right mother × Left father; L×R Left mother × Right father)

		HAND (LI ≤ 0)		Hand writing (WRITE)		FOOT		EYE		EAR	
		N	%Left	*N*	%Left	*N*	%Left	*N*	%Left	*N*	%Left
Control parents	R×R	169	7.10	160	5.63*	134	24.63	82	34.15	71	46.48*
	R×L	19	5.26	18	5.56*	24	16.67	40	37.50	55	20.00*
	L×R	19	10.53	21	19.05*	15	13.33	45	33.33	20	40.00*
	L×L	2	50.00	3	33.33*	7	42.86	13	30.77	34	23.53*
Adoptive parents	R×R	174	7.47	152	7.24	139	32.37	97	37.11	70	24.29
	R×L	17	11.76	17	11.76	21	19.05	29	24.14	54	25.93
	L×R	14	14.29	16	12.50	11	9.09	39	20.51	23	30.43
	L×L	0	0.00	0	0.00	1	0.00	7	14.29	25	12.00
Biological mother	R	197	8.63	150	8.00	—	—	—	—	—	—
	L	19	15.79	19	15.79	—	—	—	—	—	—

Significant differences in relation to parental laterality: $*p < .05$; $**p < .01$; $***p < .001$.

Degree of lateralization

Table 4 shows the Pearson correlations between the degree of lateralization of parents and offspring. Only one correlation is statistically significant; however by chance alone one would expect 1.4 significant results at the .05 level from 28 tests.

Discussion

There is little doubt that handedness runs in families, and it is tempting to presume that that finding reflects an inherited genetic disposition, particularly since the data can be modelled quite well by means of fairly simple genetic models (Annett, 1985; McManus & Bryden, 1992), and at present there are no clearly stated environmental models which can account for existing data. The conclusion of a genetic effect cannot, however, be secure

Table 4. Correlation of degree of lateralization for individuals in the study

	HAND		FOOT		EYE		EAR	
	N	*r*	*N*	*r*	*N*	*r*	*N*	*r*
Control mother–control child	213	.040	202	.035	202	−.048	202	.049
Control father–control child	211	−.037	188	.049	188	.034	188	.104
Control mother–control father	209	−.025	188	.031	188	.051	188	.030
Adoptive mother–adopted child	211	−.032	206	−.140*	206	.076	206	.054
Adoptive father–adopted child	207	.026	178	−.029	178	−.004	178	−.043
Adoptive mother–adoptive father	205	.014	178	.059	178	.007	178	.029
Biological mother–adopted child	216	−.021	—	—	—	—	—	—
Biological father–adopted child	43	−.052	—	—	—	—	—	—
Biological mothers–biological children[a]	429	.010	—	—	—	—	—	—
Biological fathers–biological children[a]	254	−.043	—	—	—	—	—	—

Significant correlations are indicated by: *$p < .05$; **$p < .01$; ***$p < .001$.
[a]i.e. control parents with control children and biological parents with adopted children.

without either direct molecular genetic evidence for a gene, or evidence from adoption studies that handedness follows biological rather than adoptive parent handedness.

The present large adoption study allows the question to be examined more carefully. However, in our data on direction of lateralization for handedness, there are no differences in association of handedness with biological and adoptive parents' handedness. However, that negative result is not strictly evidence against a genetic basis for handedness, for it is also evidence against an environmental basis; there is no significant association either with adoptive parent's handedness. The problem therefore lies in the absence of a familial association in control children.

The results comparing biological mother's handedness with offspring (control and adopted children) show that children of left-handed mothers ($N = 40$; 15.0 per cent left-handed offspring) were 2.04 times more likely to be left-handed than children of right-handed mothers ($N = 389$; 7.97 per cent left-handed offspring). Although not statistically significant ($\chi^2(1) = 2.28$, $p = .131$, two-tailed), the effect is of a similar order of magnitude to that reported elsewhere in studies of the inheritance of handedness (McManus & Bryden, 1992), in which a single left-handed parent makes children about 2.3 times more likely to be left-handed. The number of biological fathers is somewhat smaller but a similar effect can be seen: 7.92 per cent of 227 children of right-handed fathers are left-handed compared with 11.11 per cent of children of 27 left-handed fathers ($\chi^2(1) = 0.322$, n.s.), a ratio of 1.45 times.

The question is therefore whether an adoption study such as this has sufficient power to detect effects even in biological parents. If 9 per cent of parents and offspring are left-handed, and 2.3 times as many children of left-handers are left-handed as are those of right-handers (i.e. 8.2 per cent and 17.1 per cent in R×R and R×L matings) then power analysis shows for an alpha level of 5 per cent and a power of 80 per cent of detecting a significant result, a sample size of just over 1000 is necessary. To put it another way, based on the sample of 429 biological mothers in the present study the power is only 45 per cent. It is, therefore, not surprising that a significant effect was not found, and neither is

it surprising there is no significant difference for the less powerful test of detecting a significant difference between adopted and control children.

The difficulty of using adoption studies for phenomena with relatively small familial effects means that significant effects are only likely to be found by combining individual studies using meta-analytic techniques (Schmidt, 1992). The data of the CAP are, therefore, reported here in detail so that they may in the future be combined with results of other studies. The difficulty of carrying out such studies should not, however, be underestimated. DeFries *et al.* (1994) have pointed out that when the CAP was begun in the late 1970s there was a realization that it could well be the last of the large-scale prospective adoption studies, principally because the sexual revolution in the 1960s, of easier availability of effective contraception and legalized abortion, coupled with an increased willingness for unmarried mothers to keep their babies, dramatically reduced the children available for adoption. Further adoption studies of handedness will have to be retrospective, studying children who have already been adopted and are probably adult. Such strictures will make it harder to collect adequate data on parental handedness, particularly biological parents of adopted children. If the adoption design is to successfully partition laterality variance then data for existing studies need to be published for eventual combination by meta-analytic techniques.

Evidence on familial trends in *degree* of lateralization is scarcer in the literature, and shows some discrepancies. Although McManus (1979, 1985) found only a non-significant correlation of .045 between degree of handedness of parents and children, Bryden (1979, 1982) found a significant correlation of .21 and Porac & Coren (1981) found a significant correlation of .10. The present study, with a sample size of 429 for biological mothers and biological children had an 80 per cent chance of detecting a correlation of .12, and a 50 per cent chance of detecting a correlation of .08 with a two-tailed significance level of .05. The overall correlation for handedness of .01 probably represents a true absence of an effect, rather than a lack of statistical power. A comparison of the results for FOOT, EYE and EAR with those of Porac & Coren (1981) shows that the non-significant associations found in the present study between control parents and children are similar in magnitude to the values found by Porac & Coren ($r = .07$, .05 and .06 for foot, eye and ear respectively, averaging maternal and parental correlations). The barely significant results in the study of Porac & Coren (1981) in conjunction with the non-significant results in the present study force the conclusion that degree of footedness, eyedness and earedness do not run in families.

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