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Cognitive ability and hemispheric indecision: two surpluses and a deficit

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Abstract:

This paper re-examines a finding by Crow et al. (1998) showing that equal skill of right and left hands – hemispheric indecision - is associated with deficits in cognitive ability. This is consistent with the idea that failure to develop dominance of one hemisphere is associated with various pathologies such as learning difficulties. Using the same data, the British National Child Development Study, we find strong evidence of both surpluses and a deficit associated with this indecision. So no general association between indecision and cognitive ability can be drawn from this data.

1 Introduction

In a recent article Crow et al.(1998) examines the question of whether individuals who are equally good with both hands have an associated deficit in cognitive and scholastic abilities. Using data from the British National Child Development Survey (NCDS), a cohort study of children born in 1958, they find that there is a negative association between equal hand skill and scores on four tests of ability: mathematics, verbal and non-verbal reasoning and reading comprehension. It is hypothesized that this equal skill is a marker for failure to develop cerebral dominance of either hemisphere – hence the term "hemispheric indecision"- which is the cause of the cognitive deficit. This finding is comparable to the argument that individuals who are cross-lateralized, for example left-handed but right-footed, experience pathologies such as learning difficulties, for example Orton (1937) and Delacato (1966). More recent studies have tended to not find any particular disadvantage associated with cross-laterality for example McManus and Mascie-Taylor (1983) who also use the NCDS and Sulzbacher et al. (1994).

Of the numerous studies examining the cognitive correlates of handedness, the vast majority treat handedness as binary. In the Right-shift theory of Annett (2002), the notion of a continuum of handedness is central however. Moreover her theory that handedness represents a genetically balanced polymorphism suggests that there are some heterozygote advantages (+/-) relative to homozygotes (both -/- and +/+). Evidence is presented that those close to the centre of a handedness continuum do better on certain cognitive tasks, see her Figures 11.2 and 11.6 for example.

Mayringer and Wimmer (2002) have recently re-examined the Crow et al.(1998) hypothesis in a sample of 530 Austrian children using the peg-moving task of Annett (2002). They find no evidence of cognitive deficits associated with equal skill in both hands. Kopiez et al. (2006) analyse the relationship between one form of musical ability (sight reading) and a continuous measure of laterality with a sample of 52 pianists. They find a significantly higher level of performance by non-right-handers. Importantly, they find evidence of a non-linear inverted "U" shaped relationship between the outcome of interest and a measure of laterality (see their Figure 4). Fitting a quadratic curve, they find that the peak corresponds to a value of laterality close to 0. In other words it is the ambidextrous that do best: there is a cognitive surplus at the point of "hemispheric indecision". Nettle (2003) addresses some of the problems inherent in using conventional laterality quotients in re-examining the same data used by Crow et al.(1998) using multiple regression. However he finds that the latter's main result is robust to correcting for such problems. The purpose of this paper is also to re-examine the hypothesis of Crow et al.(1998) using the same data (the NCDS) but using additional measures of relative hand skill not utilized in the original study. For the theory to be robust one would expect it hold for any reasonable measure of laterality.

2 Data and methods

2.1 Data

The data for the analysis is based on the 1958 National Child Development Study (NCDS). This is a longitudinal study of all persons living in Great Britain who were born between 3rd and 9th of March 1958. We use two of the four outcomes of interest used in Crow et al. (1998): measures of verbal and non-verbal ability that are based on Douglas (1964). The results for the other two, reading comprehension and mathematics, are essentially the same and hence are omitted. They are available from the author on request.

Three measures of relative hand skill are used, that of Crow et al. (1998) and two others. In the 1969 wave of the NCDS, a doctor administered a series of tests of motor co-ordination. In one, children were required to tick as many squares as possible from a printed sheet within one minute. This was done separately with each hand. From these scores we define one measure of relative hand skill (R-L)/(R+L) which is essentially that used by Crow et al.(1998). This variable is referred to as “Square”. In a second task, children were required to bounce and catch a ball, again with both hands. The total number of times (out of ten) for each hand was recorded. Again, relative hand skill on this task is measured as (R-L)/(R+L) and is labeled “Bounce”. Finally, the children were timed picking up 20 matches. In this case we define the variable (L-R)/(R+L) as a measure of relative hand skill since a longer time with any hand is associated with lower skill. This is called “Match”.

For all three measures the means are greater than zero and are lower for mixed-handers and lower still for left-handers as one would expect. It should be noted that continuous measures of handedness such as these are distinct from measures based on aggregating over a number of distinct tasks (i.e. counting the proportion of a set of activities which are done with each hand) such as the Edinburgh Inventory (see Oldfield (1971)): one could be highly lateralized by the former and not the latter or vice versa.

McManus (1985) examines the distribution of the Match and Square task and points out some problematic features of the Match task, in particular the possibility or recording biases that may mask the extent of asymmetry. There is clear evidence of digital preference with larger number of scores ending in 0 or 5 than would be expected by chance. If this measurement error is Classical (i.e. random) then this will generate an attenuation bias on the relevant coefficient in estimates of linear models when the variable in question is a covariate. It is our contention that while the Square task may seem to be the best measure of hand skill, there is no reason not to use the others in addition. If a measure that is probably poor at picking up asymmetry shows an association with the outcome of interest then it is all the more striking a result. The Square task is not without its own problems, as pointed out by Crow et al. (1985): children who have more experience of writing (for example because of higher cognitive ability or better school attendance) may display a greater difference in hand skill.

From each of these variables one can define a binary variable indicating whether the individual was ambidextrous. This is not as straightforward as it seems. If a task is very easy then it is possible that a person will very well on both and hence equally well so a large number of individuals will appear to be ambidextrous. This is the case for Bounce as most children were able to successfully catch all ten balls hence roughly 66% of children are equally good according to this task. If one applies the same criterion for the Squares task (i.e. Square=0) then less than 1% are ambidextrous. Since it is clearly a more stringent criterion we relax it somewhat by defining an individual to be ambidextrous if $-.07 < \text{Square} < .07$. This is achieved by 13.5% of the sample. Similarly, for Match, requiring strict equality implies that 9.4% are ambidextrous. We relax this to require $-0.02 < \text{Match} < 0.02$ for an individual to be defined as ambidextrous. This is achieved by 18.7% of the sample. These variables are referred to as Square_eq, Bounce_eq and Match_eq respectively. It should be emphasized that the results are *not* sensitive to at least small changes in these bands.

As a control, we also use a measure of hand preference take at age 7, which allows for mixed-handedness. For a recent treatment of the relationship between hand preference and hand skill, see Brown et al.(2006). The correlations between the three continuous laterality measures, while positive, are not especially high, ranging from 0.16 to 0.013.

A general measure of motor coordination/skill is constructed from the six measurements take (i.e. the three tasks, with each hand). To do this, we simply use the first principle component of the six. This gives sensible results since the factor loadings are positive on the measurements for the Bounce and Square task and negative for both the Match measurements which reflect the length of time taken to complete the task. This variable, labeled "Motor", is normalized to have a mean of zero and a standard deviation of one. One could include a separate measure of motor co-ordination (i.e. R+L) for each of the three tasks but this more parsimonious specification seems satisfactory. An alternative strategy would be that of Nettle (2003) who uses (R-L) and (R+L) as covariates, the results here are not fundamentally different if one uses that approach.

2.2 Methods

To explore the relationship between hand skill and cognitive ability we first use a graphic approach by estimating the relationship between each of the four ability scores (separately) and the three hand skill variables (simultaneously) and controlling linearly for a number of covariates ("X") in this case, sex and hand preference at age 7. We use a simple back-fitting method, the Alternating Conditional Expectation algorithm of Breiman and Friedman (1985) as implemented for *Stata* by Cox and Royston (2005). This amounts to estimating a relationship of the form:

$$y_i = f_B(Bounce_i) + f_S(Square_i) + f_M(Match_i) + \beta X + \varepsilon_i$$

y_i is the score on the test in question , no assumption about the distribution of the error term (ε_i) is required. Graphs of the f(.) functions are presented along with point-wise confidence intervals. These are likely to be underestimates of the true confidence intervals. To further explore the relationship between the test scores and cognitive ability we estimate a series of linear regressions. All regressions report t ratios based on Huber/White heteroscedastic robust standard errors. Estimation is with *Stata*, version 9. The sample size for all estimates is 10,537.

3 Results

3.1 A graphical approach

For the verbal and non-verbal ability scores, the estimated relationships are shown in Figures 1 and 2 respectively. The first graph in Figure 1 shows the relationship between the verbal score and Square: the $f_S(.)$ in the equation above. The V shaped relationship centered at the point of equality confirms the finding of Crow et al.(1998) of a cognitive deficit associated with equal ability. However the second figure, which shows the $f_B(.)$ function reveals *precisely the opposite*, there is a distinct upward spike in verbal ability associated with the point of equality. The gradient is clearly greater in magnitude than for the Squares task. The last graph reveals that for the Match task there is also a positive association (albeit a rather gentle one) between verbal ability and being ambidextrous. The wide conference bands in the tails reflect the small number of observations with extreme values of laterality.

Figure 2 repeats the exercise for non-verbal ability with the same results. In short, for both tests one finds two surpluses and one deficit in cognitive ability associated with ambidexterity. While this exercise is useful for exploring graphically the relationships of interest it is not precise enough to test the theory and quantify the relationships of interest. To do that, estimates of a series of linear models are presented in the next sub-section.

3.2 A linear regression approach

In Table 1, ordinary least squares estimates of linear models of verbal and non-verbal ability are presented. The independent variables of interest are the three laterality quotients and the three dummy variables indicating equal ability with both hands (as described in section 2.1). As additional controls, dummy variables for hand preference at age 7 and sex are included. While the R-squared may seem low in these regressions this is not surprising for a large heterogeneous sample and is comparable with that found in many other NCDS studies for a variety of outcomes, for example Nettle (2003) or Denny and O'Sullivan (2006).

In the first model, of the laterality quotients, only Square is statistically significant showing a positive association between verbal ability and right-handedness on that task. The negative coefficient on Square_eq confirms, again, the finding of Crow et al. (1998) of a deficit associated with equal skill. As one would expect from Figure 1 however there are positive effects associated with equal skill for the two other tasks although that for Match is not well determined. These results are qualitatively the same for non-verbal ability. This provides further clear evidence that one cannot infer that there is, in general, a penalty associated with being ambidextrous. As noted previously, measurement error in the Match task is likely to bias the coefficient towards zero.

As is normal in this literature, these estimates rely on measures of relative skill i.e. (R-L)/(R+L). However one has to ask whether such a variable really measures what it is supposed to or whether it reflects a spurious correlation with some other, omitted variable. The obvious candidate is a measure of general motor co-ordination. Say for example one has an individual with extremely low cognitive ability and hence (by assumption) performs badly with both hands: R-L will be low but this is largely because R+L is also low. So low ability appears to be associated with being ambidextrous but is at least partly picking up poor general coordination[1]. A similar argument applies at the other tail of the distribution: a high ability individual who can do the tasks easily with both hands will appear ambidextrous but the low R-L is being driven by the fact that R+L is high[2]. To allow for this, columns 3 and 4 add the measure of motor skill/co-ordination to columns 1 and 2 respectively.

As one would expect there is a statistically significant positive association between the dependent variables and motor co-ordination and the fit of the equation, as measured by the R-square, improves dramatically. The estimate of the cognitive surplus due to ambidexterity falls substantially, from 1.475 to 0.816 in the case of verbal ability and 1.108 to 0.561 but both remain statistically significant. So while there may be some merit in the argument that the conventional measures of relative hand skill are picking up measures of absolute hand skill, it cannot explain our main result in general. It is also noticeable that the slope on the Square variable is now much bigger in both columns.

It is possible that the dummy variables do not fully capture the relationship of interest so in Table 2 an alternative method is used: linear splines. This assumes that the relationship between the dependent variable and each of the three tasks is captured by a piecewise linear function consisting of two segments connected at a point (a "knot") corresponding to a value of the independent variable specified by the investigator. Since the theory implies that 0 is the appropriate value and Figures 1 and 2 also suggest this, that is chosen as the location of the knot.

As a cognitive deficit will imply a V or U shaped relationship one expects negative and positive slopes on the first (less than 0) and second (greater than 0) splines respectively. A

[1] McManus et al.(1992) show decreased functional lateralization in a sample of children with autism.
[2] Several problems with laterality quotients are discussed in Nettle (2003) and Leask (2003).

surplus implies the opposite. The results in Table 2 are as one would expect on the basis of Table 1 and Figures 1 and 2. For both outcomes, there is a cognitive deficit associated with equal skill on the Square task and a surplus associated with both the Bounce and Match task. It is noticeable that the left (downward sloping) spline for the Square task is not statistically significant for the Verbal score which implies that it is high values only that generate a cognitive advantage. These results provide further evidence of the absence of a general deficit associated with hemispheric indecision. It is noteworthy that left-handedness (by preference) has no effect on ability but mixed handedness has a negative one, particularly for verbal ability. However if one omits all the hand-skill terms and retain just the two hand preference variables and sex then the coefficient on left-handed is a well determined negative number: for verbal ability the coefficient is –0.998 (t ratio = 3.31) and for non-verbal ability it is –0.774 (t ratio=3.19). So, whatever their deficiencies, the continuous hand-skill measures statistically dominate the mostly widely used indicator of laterality.

Some additional sensitivity analysis was carried out. There is a small number of extreme values for the measures of laterality (i.e. equal or close to 1 or –1) and since least squares regression may not be robust to outliers, the analysis was repeated with the robust regression method of Hamilton (1991), (1992). This involves initially eliminating "influential observations" (i.e. with a Cook's D value >1) and then running weighted regressions with higher absolute residuals generating lower weights. This process is iterated until convergence. A second approach is to omit extreme values of the dependent variables: we truncate the distribution of the dependent variables by omitting the highest and lowest 4% of values. In both cases, there were no substantive differences in the results. Results are available from the author on request.

4 Discussion

There is an extensive literature documenting the cognitive and behavioural correlates of handedness. Harris (1992) concluded "By now, left- and right-handers have been compared perhaps hundreds of times on dozens of different cognitive tasks, with results going in all directions." Although much has been learned since then, an updated review of the literature would hardly lead to a very different conclusion. This paper presents a challenge to one particular hypothesis, namely that the absence of hemispheric dominance, to the extent that it corresponds to being ambidextrous, leads to lower cognitive ability in general. The results here are, therefore, close to that of Mayringer and Wimmer (2002) who find an absence of cognitive deficits and perhaps closer still to that of Kopiez et al. (2006) who find a cognitive surplus. Hence they are also partly consistent with the theory of Annett (2002).

Whether results such as these can tell us anything about language dominance is unclear however. The laterality quotients used here (based on relative skill on a given task) are correlated with hand preference and it is known that hand preference is correlated with language lateralization[3] but this does not imply that relative hand skill is associated with lateralization (although it may well do). There is evidence that footedness is better a better indicator of lateralization than handedness for several functions including language[4], however adding footedness (measured at age 11) to the models here does not improve the fit.

What is perplexing here is finding both a deficit and surpluses on tasks taken on the same occasion. However while the tasks are similar they are certainly not identical and different combinations of skills may be required. The relatively low correlations between the

[3] See Knecht et al. (2000) or Annett (2002), chapter 1 for example.
[4] See Elias and Bryden (1998) and Elias, Bryden and Bulman-Fleming (1998).

laterality quotients are consistent with that. If different underlying skills are required then perhaps it is not surprising that cognitive surpluses and deficits co-exist.

While the laterality quotients used here are common, they may be misleading since the distributions of R and L may differ and may depend on which hand is dominant. A more general approach would be to analyze the joint distribution of R and L (and the outcome of interest) using some non- or semi-parametric method, for example along the lines of Leask and Crow (2001) or Leask (2003). Applying these graphical approaches to the data used here would involve estimation in a 7 dimensional space, which is problematic. So while the measures used here are not ideal we echo the view of Mayringer and Wimmer (2002) who note "Even a rough measure of hemispheric indecision should allow one to detect a negative effect in a sample of more than 500 children". The same argument applies, *pari passu*, with a sample of over 10,000. Clearly more tests of the theory with different instruments and whose properties are well understood are required to further test the underlying hypothesis. What is also needed is a theory that can predict the co-existence of cognitive surpluses and deficits.

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Table 1

Ability scores and binary indicators of equal skill

	1	2	3	4
	Verbal	**Nonverbal**	**Verbal**	**Nonverbal**
Left-handed	-0.322	-0.271	0.121	0.096
	[0.76]	[0.78]	[0.29]	[0.28]
Mixed-handed	-0.837	-0.499	-0.74	-0.418
	[2.33]	[1.66]	[2.10]	[1.43]
Square	1.982	1.287	3.531	2.569
	[1.97]	[1.58]	[3.57]	[3.20]
Bounce	0.365	0.575	0.634	0.798
	[0.32]	[0.60]	[0.59]	[0.88]
Match	-0.341	0.537	-0.826	0.136
	[0.33]	[0.65]	[0.81]	[0.16]
Square_eq	-1.641	-1.46	-1.669	-1.483
	[5.71]	[6.19]	[5.89]	[6.38]
Bounce_eq	1.475	1.108	0.816	0.564
	[7.44]	[6.89]	[4.12]	[3.51]
Match_eq	0.323	0.296	0.282	0.262
	[1.43]	[1.61]	[1.26]	[1.44]
Male	-1.861	-0.09	-1.598	0.128
	[10.46]	[0.62]	[9.07]	[0.89]
Motor			1.608	1.330
			[17.02]	[16.94]
Constant	22.559	20.636	15.364	15.392
	[83.27]	[92.97]	[83.62]	[52.32]
R-squared	0.025	0.012	0.054	0.042

Note: The binary indicators of equal skill (Square_eq…etc) are as defined in Section 2.1

Table 2

Sensitivity analysis: using linear splines

	1	2
	Verbal	**Nonverbal**
Left handed	-0.774	-0.431
	[1.60]	[1.07]
Mixed-handed	-0.986	-0.597
	[2.74]	[1.99]
Square <0	-5.922	-3.354
	[2.33]	[1.61]
Square >0	6.423	4.67
	[5.88]	[5.27]
Bounce <0	7.674	6.18
	[4.15]	[4.19]
Bounce >0	-6.274	-4.554
	[4.32]	[3.68]
Match <0	3.944	3.507
	[2.15]	[2.36]
Match >0	-4.545	-2.353
	[2.47]	[1.55]
Male	-1.904	-0.122
	[10.70]	[0.84]
Constant	23.19	21.073
	[95.82]	[106.46]
R-squared	0.022	0.009

Note: In these models the relationship between the outcome and each of the three laterality quotients is given by a piecewise linear function consisting of two segments connected at 0. So, for example, the slope of Verbal ability with respect to Square is –5.922 when Square is negative and is 6.423 when it is positive, generating a V shaped relationship.

Figure 1: Modeling verbal score, adjusting for sex and hand preference

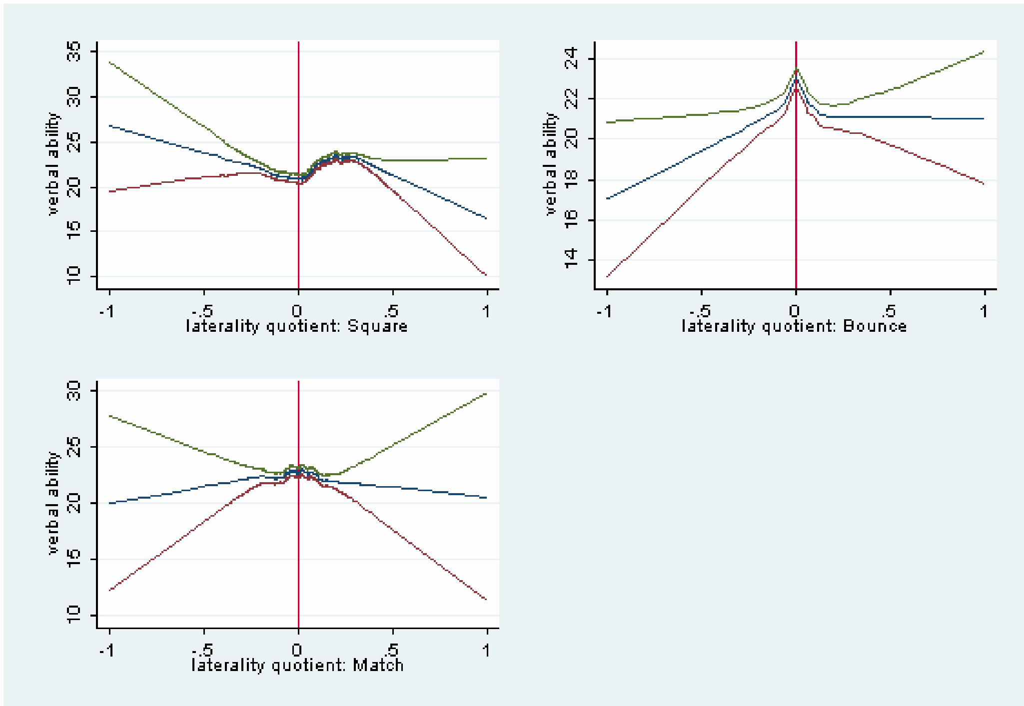

Figure 2: Modeling non-verbal score, adjusting for sex and hand preference