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Handedness, health and cognitive development: evidence from children in the National Longitudinal Survey of Youth

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Summary. Using data from the child supplement of the US National Longitudinal Survey of Youth, and fitting three-level random-effects models of child health and cognitive development, we test whether left-handed children have different outcomes from those of their right-handed counterparts. The health measures cover both physical health and mental health, and the cognitive development test scores span vocabulary, mathematics, reading and comprehension. Overall we find little evidence to suggest that left-handed children have a significantly higher probability of experiencing injury, illness or behavioural problems. In contrast, we find that left-handed children have significantly lower cognitive development test scores than right-handed children for all areas of development with the exception of reading. Moreover, we find no strong evidence that the left-handedness effect differs by gender or age.

Keywords: Children; Cognitive development; Handedness; Health; Multilevel modelling

1. Introduction

Identifying the causal factors that influence child health and cognitive development is a key task for social scientists, as childhood health and development strongly impact educational and adult outcomes. Consequently, there is a vast interdisciplinary literature that has examined a wide array of potential factors that affect child health and cognitive development (see, for example, Haveman and Wolfe (1995) and Currie (2009)). In the economics literature, a large emphasis has been on establishing the extent to which maternal employment decisions affect child development (see, for example, Blau and Grossberg (1992), Waldfogel *et al.* (2002), Ruhm (2004, 2008)

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and James-Burdumy (2005)), and many researchers have also focused on the role of parental income in determining childhood health and development (see, for example, Blau (1999), Guo and Harris (2000), Case *et al.* (2002), Aughinbaugh and Gittleman (2003), Currie and Stabile (2003) and Paxson and Schady (2007)). Although the influence of maternal employment on child health and cognitive development remains contentious, there is some consensus that children from higher income families are generally healthier and have better cognitive development than children from poorer families.

In this paper we investigate a relatively underresearched aspect of child health and development, but one that affects a large group of individuals in any population. Our contribution is to quantify better the effect that handedness, being left handed rather than right handed, has on child health and cognitive development by using panel data on US children and siblings across a variety of health and developmental measures. This is important, because handedness is known to be related to changes in brain asymmetry (Knecht *et al.*, 2000) and these asymmetries are fundamental to human cognition, behaviour and emotion (Francks *et al.*, 2007). McManus (2002) and Harris (2003) provide fascinating accounts of various aspects of the history of handedness, or brain asymmetry, going back to classical times. This is also a quantitatively important issue as there are currently around 31 million dominantly left-handed people in the USA, or roughly 10% of the population, which is about the size of the population of California (see, for example, Bryden *et al.* (1997), Denny and O'Sullivan (2007) and Ruebeck *et al.* (2007)). However, this percentage can differ depending on exactly how handedness is measured and on the sampling method used (Llaurens *et al.*, 2009).

A better understanding of the effect of handedness on child health and cognitive development, and whether handedness differentials change with age, will help to explain any observed educational and labour market differentials. Two recent references have investigated the relationship between left-handedness and earnings (Denny and O'Sullivan, 2007; Ruebeck *et al.*, 2007), although their results are mixed. Denny and O'Sullivan (2007) found that left-handed men in Britain earn approximately 5% more than right-handed men, and that this premium is slightly higher for non-manual workers. Yet they found no evidence that individuals sort into different types of occupations based on handedness. Their results are opposite for women, with left-handed women earning about 4% less per hour than their right-handed equivalents. Using US data, Ruebeck *et al.* (2007) also found a positive wage effect for left-handed men with high levels of education. Moreover, their estimated differential is quite large as left-handed males with a college level education earn 15% more than right-handed males. Unlike Denny and O'Sullivan (2006), however, they found no significant wage effect for women. Faurie *et al.* (2008) explored the relationship between socio-economic status and handedness in two cohorts of French data. They found only weak correlations between handedness, education and income, with left-handers being slightly over-represented in higher education levels (only for females) and higher income groups.

In this study we use data from the child supplement to the US National Longitudinal Survey of Youth (NLSY), which enables us to improve on previous studies that investigate the effects of handedness on child health and development outcomes. Firstly, the multilevel nature of the NLSY data means that we observe families that have both left- and right-handed children, and we estimate several random-effects (or random-intercept) models of child health and development. As far as we know, this is the first paper of its kind that controls for unobservable family heterogeneity in this context. Secondly, since the data track children from birth to adolescence we can test whether the health or development differentials by handedness increase or decrease, as children grow older. Thirdly, the data contain a variety of well-established test scores so we can test whether left-handed children differ from right-handed children with respect to various aspects of cognitive development, as well as in their probabilities of experiencing serious illness, injury or behavioural problems.

2. Causes of handedness and their consequences for health and development

It quickly becomes apparent from reading the literature, both on the causes and the consequences of handedness, that much is still open to debate. Part of this disagreement, particularly regarding the consequences of handedness, appears to arise because many of the studies draw their conclusions from small, typically non-random, samples of children. This problem is combined with a lack of consistent measurement of child outcomes, making it difficult to compare studies reasonably (Faurie *et al.*, 2006). We attempt to tackle both these problems in our analysis, using a large widely used representative longitudinal survey together with accepted measures of child outcomes. Given the large multidisciplinary literature on the theories and empirics of handedness, we can give only a selected review, focusing on what we think are the most important studies.

2.1. Origins of handedness

There are various proposed theories and a large number of empirical studies that attempt to explain the origins of handedness (i.e. why are some people left handed whereas the majority of the population is right handed?). Broadly, we can divide these various theories on the origins of handedness into those purporting

(a) a genetic explanation,
(b) exogenous factors (such as brain insult or exposure to androgens) and
(c) the social environment

(see Johnston *et al.* (2009) and Vuoksimaa *et al.* (2009) for reviews). Perhaps the most agreed-on finding is the strong genetic link for the intergenerational transfer of handedness. In particular, compared with a child with two right-handed parents, a child with one left-handed and one right-handed parent is 2–3 times more likely to be left handed, and this ratio increases to 3–4 for a child who has two left-handed parents (Bryden *et al.*, 1997). Recent work has focused on whether the gene LRRTM1 on chromosome 2p12 is the genetic factor in determining handedness, and whether this gene provides a direct link between handedness and schizophrenia (Francks *et al.*, 2007). However, this link has been strongly contested (see Crow *et al.* (2007) and Francks (2009)).

Among exogenous factors, a popular hypothesis proposes that the fetal environment and particularly the experience of stress relating to birth are important in explaining handedness (Bakan *et al.*, 1973). A proportion of individuals may suffer some minor brain insult either prenatally or perinatally and this causes a cognitive decline as well as a shift towards right hemisphere dominance—leading to left-handedness. In examining the determinants of handedness in twins, James and Orlebeke (2002) showed that there must be at least one environmental determinant of handedness, and that left-handedness is strongly associated with low birth weight. Also, Rodriguez and Waldenström (2008) found that prenatal exposure to maternal depressive symptoms and critical life events are associated with increased risk of non-right-handedness. However, other studies have found that prenatal or perinatal brain insult probably accounts for only a small proportion of left-handers (Satz *et al.*, 1985). For example, Bailey and McKeever (2004) found that out of 25 potential ‘stressors’ only maternal age shows a significant relationship with left-handed offspring. Similarly, Salvesan and Eik-Nes (1999) explored the effect of ultrasound during pregnancy and non-right-handedness and found no statistical link between the two, except for a subgroup of boys. Another exogenous factor is prenatal exposure to androgens, such as testosterone, which causes an increase in the incidence of left-handedness (Geschwind and Behan, 1982). Support for the role of androgens comes from clinical studies showing an elevated incidence of left-handedness in children who have been exposed to abnormally high levels of testosterone (Kelso *et al.*, 2000).

Social environment theories propose that children are born into a right-handed world and that the models they observe, the tools they use and social stigmatism encourage them to be right handed (Porac and Coren, 1981). Alongside genetics, social environment may also play an important role in the intergenerational transfer of handedness within families. Clear environmental effects can be seen in cross-cultural studies of hand preference (Medland *et al.*, 2004). In countries with a non-formal educational regime, the incidence of left-handedness is 11.9%, whereas in more conservative, formal cultures the incidence of left-handedness drops to 8.9%. However, although hand preference can be affected by social environment, it is unlikely that it is determined entirely by culture. If handedness is socially constructed, we might expect at least one culture where left-handedness predominates—and this does not appear to be so. In addition, the fact that right-handedness has prevailed since prehistoric times, perhaps dating back to *homo habilus* 2.5 million years ago (Toth, 1985), militates against a cultural explanation.

2.2. Handedness and health outcomes

Handedness has been associated with various traits and outcomes during a person's lifetime. Among these, a large medical and psychological literature has developed theories and undertaken empirical work to understand whether there is a relationship between handedness and health outcomes (see Bryden *et al.* (2005) for a review). Although an association between handedness and health outcomes has been observed, not only for *mental health*, but also for *general health*, the findings are not unanimous and are often limited to adult populations. Some key references in this area are Bishop (1986), Bryden *et al.* (1991, 2005), Coren and Halpern (1991) and Coren (1994).

With regard to the role of handedness in explaining mental health, it has been argued that birth stresses, which lead to a shift of dominance from the left to the right hemisphere, result in increased mental illness, such as schizophrenia. Recently, Denny (2009), analysing large population survey data from 12 European countries, found that left-handed adults are significantly more likely to experience depressive symptoms than right-handers. However, the evidence supporting increased schizophrenia among pathological left-handers has been mixed (see Green *et al.* (1989) and Claridge *et al.* (1998)). There may be an association, however, between a weak hand preference to either the left or right and schizotypical personality traits in the general population (Nicholls *et al.*, 2005).

General health may also be affected by an individual's hand preference. Bryden *et al.* (2005) found an association between hand preference and epilepsy, heart disease, thyroid disorders and allergies, though the samples that were used for the analysis were very small. Health problems such as these might lead to the reduced longevity for left-handers that was reported by Halpern and Coren (1988). However, the finding of a lower life expectancy among left-handers has not been supported by numurous other studies (see, for example, Ellis *et al.* (1998), Peto (1994), Steenhuis *et al.* (2001) and Berdel Martin and Barbosa Freitas (2003)) and the effect itself may reflect the history of the individual and the educational–social regime in which they developed (Hugdahl *et al.*, 1993). Handedness might have a specific relationship with the immune system. Important in this relationship is the role that testosterone *in utero* has in retarding the development of the left hemisphere of the brain leading to a higher likelihood of being left handed and a greater susceptibility to certain illnesses (see Geschwind and Behan (1982, 1984) and also Bryden *et al.* (2005)).

Besides affecting a person's intrinsic health, it has also been suggested that left-handed individuals suffer from more health problems caused by injuries (Coren, 1989, 1996). This could be due to differences in brain functioning, relating to the degree of spatial awareness, such as clumsiness (Bishop, 1980), or environmental factors relating to left-handers living and working in environments that are designed for right-handers. For example, Reio *et al.* (2004) found significant differences in various aspects of spatial ability, with three-dimensional rotation and speeded visual exploration slightly favouring left-handers, but spatial location memory favouring right-handers. Porac and Coren (1981) collected numerous anecdotal reports that, because tools, machinery and even traffic patterns have been designed for the convenience of right-handers, left-handers may be more subject to accidental injuries. Porac and Coren (1981) even went on to suggest that individually or cumulatively these accidents could result in reduced longevity. Coren (1996) found that non-right-handers have a greater risk of bone breaks and fractures than right-handers, whereas Dutta and Mandal (2006) found that left-handers have more driving accidents, whereas right-handers have more sports accidents. However, Pekkarinen *et al.* (2003), analysing a sample of about 8500 men and women from Finland, found no significant difference in involvement in injury between left- and right-handers. The finding is also supported by Merckelbach *et al.* (2006).

2.3. *Handedness and cognitive ability*

In terms of handedness and cognitive ability, there are also theoretical arguments that predict differences in the cognitive abilities of left- and right-handed individuals. Some theories predict higher abilities for left-handed children (see, for example, Benbow (1986), Halpern *et al.* (1998) and McManus (2002)) whereas conversely others predict lower abilities (Annett, 1985; Bakan *et al.*, 1973; McManus and Mascie-Taylor, 1983; Resch *et al.*, 1997). Annett (1985) proposed a genetic model of handedness that predicts lower cognitive abilities for left-handers. This model proposes that handedness is controlled by a gene with two alleles, one of which is dominant whereas the other is recessive. It is argued that the recessive gene, which causes left-handedness, is maintained in the population because of a heterozygous advantage when the two alleles mix, not because it is advantageous in its own right.

Evidence for a general cognitive disadvantage for non-right-handers compared with right-handers was reported by McManus and Mascie-Taylor (1983). Resch *et al.* (1997) also reported lower levels of achievement in left-handers in spelling, educational success and non-verbal intelligence. Johnston *et al.* (2009) found that left-handed Australian children do significantly worse in nearly all measures of child development, with the relative disadvantage being larger for boys than for girls. In contrast, Faurie *et al.* (2006), using a sample of children from French public schools, found only very weak correlation (0.1) between handedness and a single measure of student performance. Using a sample of 1022 children aged 3–6 years, Dellatolas *et al.* (2003) also found that laterality is only weakly associated with children's cognitive ability. Vlachos and Bonoti (2004) found no significant differences in performance across four drawing-related tasks by handedness, although the study used only a sample of 182 children aged between 7 and 12 years.

In contrast with theories proposing that left-handers are generally disadvantaged relative to right-handers, McManus (2002) suggested that left-handedness bestows a cognitive advantage. This proposition is based on a genetic theory where handedness is controlled by a gene with two alleles, one of which is dominant whereas the other is recessive. Unlike Annett (1985), however, McManus argued that the recessive gene, which causes left-handedness, persists because it is cognitively advantageous. In support of a left-handed advantage, Benbow (1986) found an excess of gifted children among individuals who are left handed. Halpern *et al.* (1998) also found that left-handers have higher scores for verbal reasoning tests and are over-represented in the upper tail of the distribution. There may also be more general cognitive advantages for left-handers for traits such as divergent thinking (Coren, 1995), although this relationship was observed for males only. Conversely, Piro (1998) found no difference in mean handedness scores between 657 gifted and non-gifted children. Similarly, Johnston *et al.* (2009) found no evidence that left-handedness children are more likely to be especially gifted children across a wide range of developmental test scores.

3. Data, definitions and sample characteristics

Our empirical analysis uses data from the child supplement of the NLSY, which is a survey focused exclusively on children whose mothers are respondents in the NLSY. The NLSY began with a sample of 12686 Americans who were 14–22 years old in January 1979. The survey oversamples African-Americans, Hispanics, low income whites and military personnel. These initial respondents were then interviewed annually from 1979 to 1994, and biennially from 1994 to 2006. In 1986 the child supplement to the NLSY began and, in every even-numbered year since, the NLSY supplement collected detailed information on all children born to and living with a female NLSY respondent, including information on health and cognitive development assessments. The NLSY supplement cognitive development data have been widely used in various literatures—for example, see Argys *et al.* (1998), Guo and Harris (2000), James-Burdumy (2005) and Case and Paxson (2008). From the 2006 wave, the child sample contained 10992 children from 4615 families. Although these children cannot be considered a nationally representative sample of children, they are representative of the population of offspring born to US women who were aged 14–22 years in 1979 (Wu and Li, 2005). By current longitudinal survey standards, sample attrition is modest. A 2004 study found that, of the children known to have been born to NLSY women, less than 5% have not appeared in the NLSY child supplement. In most cases this is because the children's mothers were not interviewed (Aughinbaugh, 2004). Furthermore, children for whom information was collected at all NLSY child supplement interviews have similar family backgrounds to those children for whom information was collected only in some years.

In this paper, child handedness is determined by his or her mother's response to the question 'Which hand does child use for writing?' to which mothers could respond 'left, right or both'. This question was asked in surveys between 1996 and 2006, and so children with multiple responses are allocated handedness based on their latest response (the average age that handedness is measured is 13 years). Using the latest response limits measurement error arising from the fact that some children may have not fully revealed their dominant handedness at an early age. According to this measure, approximately 10% of the children are left handed, which corresponds to international averages from other survey data. In our analysis we omit mixed handed (or both handed) children from the sample because the sample size for this group is small (only 99 children).

It is important to note that it could be that some children have been forced to become right handed in groups or communities where being left handed has traditionally been associated with a cultural stigma. Although we cannot test for this possibility directly in our analyses, we believe that any such bias would probably lead us to underestimate the extent of any development differentials between right- and left-handed children. However, we do not expect that this bias is large as the data suggest that the numbers of 'forced' right-handers is small. For example, in 1998, 2137 older children from the NLSY were asked 'As a child, were you ever forced to change the hand with which you write?'. Only 2.6% of the children replied yes.

Children's health is measured by using mothers' responses to the questions 'In the past 12 months, has child had any illnesses that required medical attention or treatment?' and 'In the past 12 months, has child had any accidents or injuries that required medical attention?'. These two questions were asked every 2 years for all children from birth to age 14 years, and so for each child we have on average 5.6 responses for each health measure. Across years, the estimated probability of reporting an illness is 34% and the estimated probability of reporting an injury is 10%.

Children's mental health is assessed by using the behaviour problems index (BPI). The BPI consists of a 28-item maternal questionnaire and measures the frequency and types of behaviour problems that are manifested by children aged 4–14 years in the previous 3 months. Items include both internalizing behavioural problems, such as 'child complains no one loves him/her', and externalizing behavioural problems, such as 'child bullies or is cruel/mean to others', with mothers responding with either not true (0), sometimes true (1) or often true (2) to each item. The responses on the 28 items are summed and then standardized to form the BPI, which rises with increasing behavioural problems. We further scale the scores such that they have a mean of 100 and a standard deviation of 10. The BPI questionnaire was repeated every 2 years since 1986 and so for some children we have six BPI measurements; however, the average number of measurements for our estimation sample is 4.1.

Child cognitive development is measured by using four tests administered since 1986:

(a) the Peabody individual achievement test (PIAT) of mathematics, which assesses early mathematic skills, such as recognizing numerals, and also more advanced concepts in geometry and trigonometry;
(b) the PIAT of reading recognition, which assesses skills such as matching letters, naming names and reading single words aloud;
(c) the PIAT of reading comprehension, which assesses the child's ability to derive meaning from sentences that are read silently;
(d) the Peabody picture vocabulary test (PPVT), which assesses receptive vocabulary for standard American English and provides a quick estimate of verbal ability and scholastic aptitude.

These tests have been found to be correlated with alternative measures of cognitive development, and each has high completion rates—see Baker *et al.* (1993) for a detailed discussion of each test. In our analysis, we use PIAT scores for children aged 5–14 years and PPVT scores for children aged 3–11 years. These ages are based on the ages of the children that the tests were mostly administered to. Children completed age appropriate versions of the tests on several occasions, giving an average of 3.8 test scores for mathematics and reading recognition. Since the four test types (vocabulary, mathematics, PIAT-M, reading recognition, PIAT-R, and comprehension, PIAT-C) have different scales and, for ease of interpretation, we rescale each score to have a mean of 100 and a standard deviation of 10.

Our estimation sample contains 6566 children aged less than 14 years with non-missing health and covariate information (e.g. handedness and mother's education). The 6566 children are from 3275 families, and given the longitudinal nature of the data there are 36837 child-year observations. Table 1 describes the sample by reporting sample proportions and frequencies for binary variables, means and standard deviations for continuous variables, and medians and interquartile ranges for count variables. These descriptive statistics are reported at three age points (5–6, 9–10 and 13–14 years) for each outcome variable and covariate. The continuous

Table 1. Description of outcome variables and covariates by age†

	Results for aged 5–6 years		*Results for aged 9–10 years*		*Results for aged 13–14 years*	
	%	*Frequency*	*%*	*Frequency*	*%*	*Frequency*
Binary outcomes						
Illness in past year required medical attention	36.36	1996	27.22	1519	23.12	885
Injury in past year required medical attention	9.58	526	11.14	622	12.43	476
	Mean	*Standard deviation*	*Mean*	*Standard deviation*	*Mean*	*Standard deviation*
Continuous outcomes						
BPI	100.00	10.00	100.00	10.00	100.00	10.00
Vocabulary test score PPVT	100.00	10.00	100.00	10.00	—	—
Mathematics test score PIAT-M	100.00	10.00	100.00	10.00	100.00	10.00
Reading recognition test score PIAT-R	100.00	10.00	100.00	10.00	100.00	10.00
Reading comprehension test score PIAT-C	100.00	10.00	100.00	10.00	100.00	10.00
	%	*Frequency*	*%*	*Frequency*	*%*	*Frequency*
Binary covariates						
Writes with left hand	10.84	595	10.46	584	10.37	397
Gender is male	50.92	2795	50.04	2793	50.63	1938
Birth weight was less than 2500 g	7.52	413	7.67	428	7.86	301
Gestational period was less than 37 weeks	12.01	659	11.79	658	11.70	448
Birth involved a Caesarean section	23.70	1301	21.72	1212	20.95	802
Breast fed for any length of time	48.84	2681	45.26	2526	41.51	1589
African-American	30.19	1657	32.50	1814	34.80	1332
Hispanic	21.33	1171	20.53	1146	20.45	783
Mother drank during pregnancy	30.92	1697	31.82	1776	31.74	1215
Mother smoked tobacco during pregnancy	24.78	1360	26.55	1482	28.06	1074
Mother is left handed	9.49	521	9.62	537	9.30	356
Mother is mixed handed	1.13	62	1.22	68	1.10	42
	Median	*Interquartile range*	*Median*	*Interquartile range*	*Median*	*Interquartile range*
Count covariates						
Age in years	6	1	10	1	13	1
Age in years squared	36	11	100	19	169	27
Number of older siblings in household	1	2	1	1	1	1
Number of younger siblings in household	0	1	1	1	1	2
Mother's age at birth of child	26	7	25	8	24	7
Mother's years of completed education	12	2	12	2	12	3
	Mean	*Standard deviation*	*Mean*	*Standard deviation*	*Mean*	*Standard deviation*
Continuous covariates						
Mother hours worked in 2 years after birth ($\times 10^3$)	0.97	1.69	0.82	1.58	0.72	1.51
Mother percentile in aptitude test	0.39	0.28	0.37	0.28	0.35	0.27
log(household net income) in 2005 prices	10.53	1.02	10.53	0.96	10.53	0.97

†The sample sizes used to calculate the covariate summary statistics at ages 5–6, 9–10 and 13–14 years are 5489, 5581 and 3828 respectively.

Table 2. Health and development outcomes separately for left- and right-handed children by age†

Score	*Results for aged 5–6 years*		*Results for aged 9–10 years*		*Results for aged 13–14 years*	
	Left handed	*Right handed*	*Left handed*	*Right handed*	*Left handed*	*Right handed*
Illness	35.1%	36.5%	27.6%	27.2%	23.4%	23.1%
	[595]	[4894]	[584]	[4997]	[397]	[3431]
Injury	9.9%	9.5%	10.6%	11.2%	14.9%	12.2%
	[595]	[4894]	[584]	[4997]	[397]	[3431]
BPI	100.442	99.946	100.069	99.992	100.017	99.998
	[556]	[4583]	[545]	[4688]	[378]	[3244]
PPVT	99.504	100.062	99.454	100.064	—	—
	[237]	[1885]	[364]	[3108]		
PIAT-M	99.131	100.108‡	99.784	100.025	99.225	100.091
	[570]	[4591]	[541]	[4687]	[366]	[3106]
PIAT-R	100.176	99.978	99.489	100.059	99.690	100.036
	[562]	[4505]	[544]	[4683]	[365]	[3110]
PIAT-C	100.682	99.917	98.599	100.163§	98.666	100.156§
	[230]	[1882]	[536]	[4619]	[361]	[3087]

†Figures are sample proportions for binary outcomes, and sample means for continuous outcomes. Sample sizes are presented in square brackets. The significance levels are from two-group proportion z-tests (for binary variables) and two-group mean comparison t-tests (for continuous variables).
‡Significance at the 0.05 level.
§Significance at the 0.01 level.

outcome variables have been standardized to have mean 100 and standard deviation 10 at each age level, which is reflected in Table 1, whereas illness decreases with age and injuries increase with age. There is an approximately even split of male and female children, around a third of children are African-American and a fifth are Hispanic, the average number of siblings is almost 2, the average mother's age at birth is 25 years and the average log-household-income is 10.5.

Table 2 presents mean (or proportions for the two binary health measures) values of health and cognitive development separately by handedness and age. According to two-group mean comparison t-tests or two-group tests of proportions, the only statistically significant differences are for the PIAT of mathematics and the PIAT of reading comprehension scores, which both indicate that right-handed children score significantly higher than left-handed children. None of the health differences are statistically different from 0.

The effect of handedness on child development is further explored in Fig. 1, which presents kernel density estimates graphed separately for left- and right-handed children. For the continuous BPI measure, which rises with increasing behavioural problems, the estimates suggest that left-handed children are more likely to be observed in the upper tail of the BPI distribution, i.e. have more behavioural problems. Fig. 1(b) shows kernel densities of cognitive development (the mean of the four test scores) and demonstrates a distinct difference between left- and right-handed children. The left-handedness effect for cognitive development primarily shifts the density from the middle of the distribution to the lower tail, rather than shifting the whole distribution leftwards. In other words, left-handedness increases the probability that some

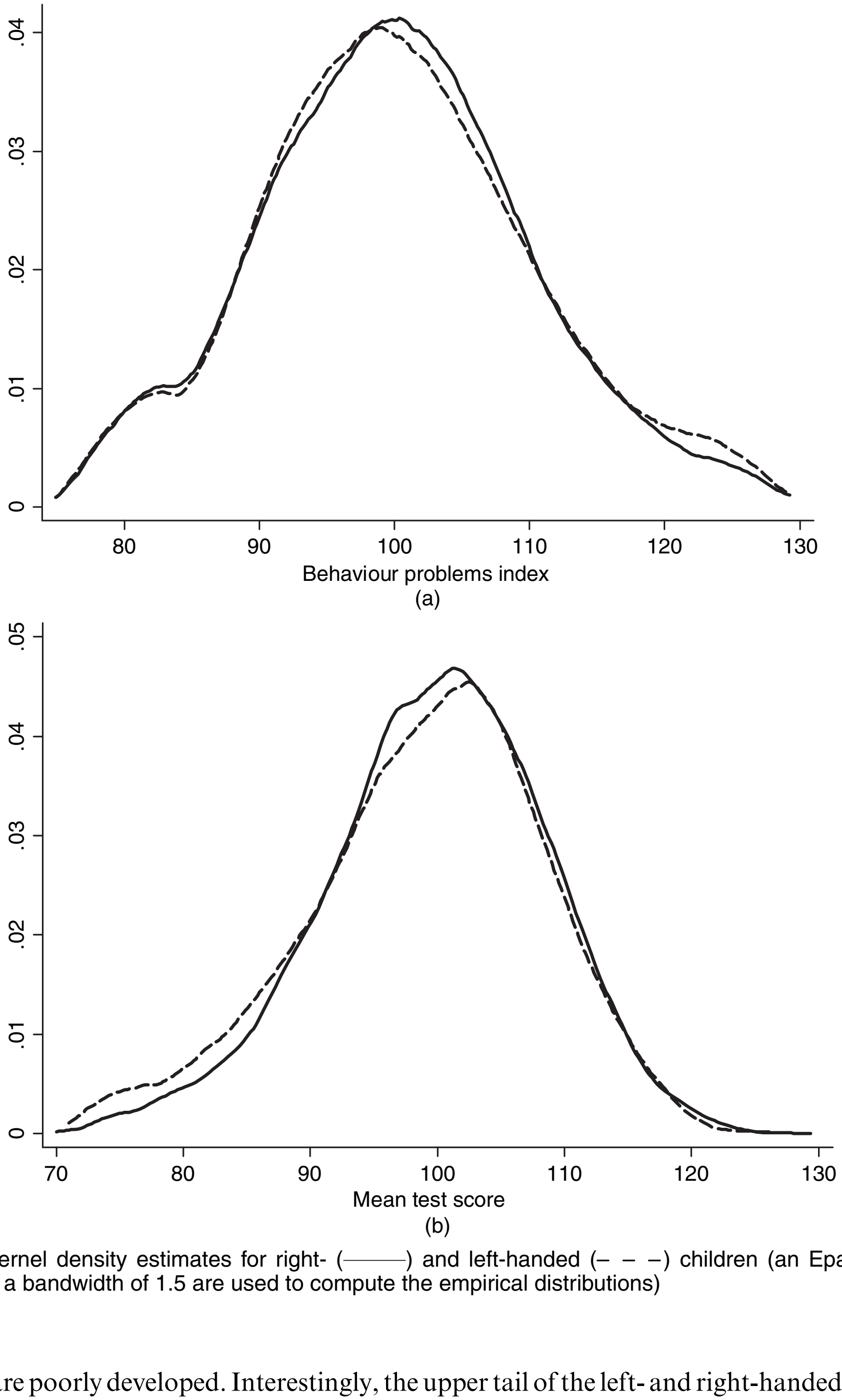

Fig. 1. Kernel density estimates for right- (———) and left-handed (– – –) children (an Epanechnikov kernel and a bandwidth of 1.5 are used to compute the empirical distributions)

children are poorly developed. Interestingly, the upper tail of the left- and right-handed test score distributions are very similar, contradicting the widespread theory that especially gifted children are more likely to be left handed. The main aim of this paper is to determine whether these differences also emerge once we control for observable and unobservable differences between left- and right-handed children and their families.

4. Effect of left-handedness on health and cognitive ability

4.1. Modelling approach

To understand how child handedness impacts on child development we regress child health and cognitive outcomes on handedness. Our general model is a three-level random-intercept regression model with the outcome in year i nested in child j who is nested in family k:

$$d_{ijk} = \mu_{jk} + \alpha_1 \,\mathrm{lh}_{jk} + \alpha_2 \,\mathrm{XC}_{ijk} + \alpha_3 \,\mathrm{XF}_{ik} + \varepsilon_{ijk} \tag{1}$$

where d_{ijk} is one of the development outcomes that were discussed in Section 3 and lh_{jk} is a binary variable indicating left-handedness. Therefore the coefficient α_1 is the parameter of primary interest and represents the effect that left-handedness has on health or cognitive development. XC_{ijk} is a vector of child-specific observed covariates that vary between children within families in the same year (e.g. gender, age, low birth weight, premature birth, Caesarean section birth, breast fed, mother's age at birth, mother's labour supply and whether the mother smoked or drank during pregnancy). The XF_{ik}-vector includes family level characteristics that vary across time and families, but not across children within the same family in the same year (e.g. race, number of siblings, mother's handedness, mother's education and income). Finally, ε_{ijk} represents unobserved factors that vary between observations, children and families, and μ_{jk} is a random intercept that varies between children j and families k.

This intercept is specified with the level 2 model $\mu_{1jk} = \mu_{2k} + \omega_{jk}^{(2)}$ and the level 3 model $\mu_{2jk} = \mu_3 + \omega_k^{(3)}$. After substitution we obtain

$$d_{ijk} = \mu_3 + \alpha_1 \,\mathrm{lh}_{jk} + \alpha_2 \,\mathrm{XC}_{ijk} + \alpha_3 \,\mathrm{XF}_{ik} + \omega_{jk}^{(2)} + \omega_k^{(3)} + \varepsilon_{ijk} \tag{2}$$

where $\omega_{jk}^{(2)} \sim N(0, \varphi^{(2)})$ is a random intercept varying over children within families $\omega_{jk}^{(3)} \sim N(0, \varphi^{(3)})$ is a random intercept varying over families and $\omega_{jk}^{(2)}$ and $\omega_{jk}^{(3)}$ are assumed independent of each other and also assumed independent of lh_{jk}, XC_{ijk} and XF_{ik}.

To accommodate the binary nature of our physical health outcome measures (illness and injury), the linear three-level model that is represented in equation (2) is replaced with a logit three-level model. Written as a latent response model, the three-level logit model for binary health outcomes is specified as

$$h_{ijk}^{*} = \beta_0 + \beta_1 \,\mathrm{lh}_{jk} + \beta_2 \,\mathrm{XC}_{ijk} + \beta_3 \,\mathrm{XF}_{ik} + \omega_{jk}^{(2)} + \omega_k^{(3)} + \nu_{ijk} \tag{3}$$

where ν_{ijk} has a logistic distribution with variance $\pi^2/3$. As for a single-level logit, the observed binary outcomes are assumed to be generated from a threshold model: $d_{ijk} = 1$ if $d_{ijk}^{*} > 0$, and $d_{ijk} = 0$ otherwise. Log-likelihood calculations for fitting multilevel random-intercept regression models require integrating out the random effects. For the linear specification this integral has a closed form solution, but this is not true for the logit model. Thus, the log-likelihood for this model is approximated by adaptive Gaussian quadrature, and 15 quadrature points are used for each level of the model.

4.2. Estimation results

The coefficient estimates from the models for the three health-related outcomes and four development test scores are presented in Table 3, and all reported standard errors that take account of the lack of independence across children within families and are robust to heteroscedasticity. The estimates in Table 3 illustrate that, for the health outcomes, illness, injury and BPI are not significantly different from 0, and hence indicate that left-handedness does not

Table 3. Maximum likelihood estimates of three-level random-intercept regression models†

	Estimates for health			*Estimates for cognitive development*			
	Illness, (1)	*Injury, (2)*	*BPI, (3)*	*PPVT, (4)*	*PIAT-M, (5)*	*PIAT-R, (6)*	*PIAT-C, (7)*
Left handed	0.073	0.085	0.330	−0.623‡	−0.660‡	−0.243	−0.799§
	(0.049)	(0.063)	(0.265)	(0.272)	(0.276)	(0.295)	(0.291)
Male	−0.053§§	0.416§	−0.626§	−0.298§§	0.213	−1.831§	−1.317§
	(0.030)	(0.040)	(0.162)	(0.165)	(0.169)	(0.181)	(0.178)
Age	−0.138§	0.092§	−0.311§	0.549§	0.355§	−0.400§	0.608§
	(0.012)	(0.018)	(0.088)	(0.150)	(0.117)	(0.109)	(0.162)
Age squared	0.002§	−0.004§	0.011‡	−0.029§	−0.011§	0.028§	−0.021‡
	(0.001)	(0.001)	(0.005)	(0.010)	(0.006)	(0.006)	(0.008)
Low birth weight	0.038	−0.238§	0.517	−0.390	−0.757‡	−0.795‡	−0.937‡
	(0.067)	(0.090)	(0.350)	(0.353)	(0.355)	(0.380)	(0.375)
Premature birth	0.083	0.082	−0.092	−0.359	−0.421	−0.389	−0.108
	(0.053)	(0.067)	(0.289)	(0.290)	(0.292)	(0.313)	(0.308)
Caesarean section birth	−0.014	−0.084§§	−0.201	−0.306	−0.701§	−0.514‡	−0.861§
	(0.045)	(0.051)	(0.253)	(0.235)	(0.233)	(0.251)	(0.245)
Breast fed	0.103‡	−0.038	−0.313	0.830§	0.640§	0.497‡	0.695§
	(0.040)	(0.046)	(0.224)	(0.213)	(0.212)	(0.228)	(0.222)
Drinking while pregnant	−0.022	0.063	0.659§	0.148	0.214	0.067	−0.071
	(0.037)	(0.044)	(0.204)	(0.200)	(0.201)	(0.216)	(0.211)
Smoking while pregnant	0.162§	0.164§	1.559§	0.568‡	0.071	−0.258	0.062
	(0.046)	(0.050)	(0.250)	(0.234)	(0.231)	(0.249)	(0.242)
Mother hours worked	0.003	−0.022§§	−0.059	−0.058	−0.003	−0.057	−0.071
	(0.011)	(0.013)	(0.061)	(0.060)	(0.060)	(0.064)	(0.063)
African-American	−0.683§	−0.556§	−0.114	−5.610§	−2.653§	−0.653‡	−1.536§
	(0.060)	(0.062)	(0.346)	(0.299)	(0.287)	(0.311)	(0.300)
Hispanic	−0.255§	−0.291§	−0.551	−3.700§	−1.636§	0.133	−0.207
	(0.062)	(0.062)	(0.365)	(0.313)	(0.303)	(0.328)	(0.317)
Number of older siblings	−0.221§	−0.043§§	−0.073	−1.377§	−0.848§	−1.223§	−1.337§
	(0.021)	(0.023)	(0.111)	(0.105)	(0.103)	(0.109)	(0.110)
Number of younger siblings	−0.202§	−0.180§	0.152	−0.746§	−0.415§	−0.375§	−0.476§
	(0.022)	(0.026)	(0.096)	(0.104)	(0.093)	(0.095)	(0.101)
Mother's age at birth	−0.006	−0.030§	−0.225§	0.092§	0.221§	0.209§	0.091§
	(0.005)	(0.005)	(0.024)	(0.024)	(0.023)	(0.024)	(0.024)
Mother left handed	0.024	0.029	−0.105	−0.240	0.102	−0.352	−0.070
	(0.073)	(0.071)	(0.430)	(0.365)	(0.352)	(0.382)	(0.369)
Mother mixed handed	0.292	0.385‡	2.238§§	−2.604‡	−2.429‡	−2.791§	−3.289§
	(0.212)	(0.185)	(1.251)	(1.026)	(0.991)	(1.081)	(1.041)
Mother's education	0.019§§	0.023§§	−0.198§	0.384§	0.327§	0.274§	0.285§
	(0.011)	(0.012)	(0.056)	(0.056)	(0.050)	(0.052)	(0.054)
Mother's armed forces qualification test	0.725§	0.461§	−1.775§	8.460§	8.988§	9.700§	9.353§
	(0.110)	(0.111)	(0.629)	(0.558)	(0.534)	(0.573)	(0.560)
Log-household-income	0.005	−0.043§§	−0.385§	0.249§	0.145‡	0.032	0.281§
	(0.019)	(0.024)	(0.068)	(0.093)	(0.071)	(0.067)	(0.081)

(*continued*)

impact on health measured in childhood. In contrast, the left-handed estimates for the cognitive development outcomes PPVT, PIAT-M and PIAT-C are all significantly different from 0. Left-handers are estimated to score approximately 6% of a standard deviation lower on vocabulary tests, approximately 7% of a standard deviation lower on mathematics tests and approximately 8% of a standard deviation lower on reading comprehension tests. Although the

Table 3 (*continued*)

	Estimates for health			*Estimates for cognitive development*			
	Illness, (1)	*Injury, (2)*	*BPI, (3)*	*PPVT, (4)*	*PIAT-M, (5)*	*PIAT-R, (6)*	*PIAT-C, (7)*
Sample size	36837	36837	26841	13335	24119	24013	20567
Log-likelihood	−21016	−11856	−93061	−45675	−83112	−81635	−70398
Family level standard deviation	0.928	0.513	5.843	4.136	3.678	4.107	3.614
Child level standard deviation	0.138	0.397	4.185	3.763	4.921	5.517	4.783
Observation level standard deviation	1.814	1.814	6.401	5.944	6.272	5.743	6.033
Family level intraclass correlation	0.207	0.071	0.368	0.256	0.175	0.210	0.180
Child level intraclass correlation	0.211	0.113	0.557	0.469	0.489	0.589	0.496

†Figures in columns (1) and (2) are coefficient estimates from logit models. All other figures are coefficient estimates from linear models. Standard errors are presented in parentheses. Illness and injury are binary variables for illness and injury in the past year. PIAT-M, PIAT-R and PIAT-C are PIAT scores in mathematics, reading recognition and reading comprehension.

‡Significance at the 0.05 level.

§Significance at the 0.01 level.

§§Significance at the 0.10 level.

coefficient on reading recognition is negative, it is smaller than the other outcomes and not statistically significant. These results are consistent with the findings of Johnston *et al.* (2009) using a large sample of young Australian children. Importantly, these results are also robust to the multiple-comparisons problem, which arises because we test for handedness differentials across seven outcomes. If we use the Benjamini and Hochberg (1995) approach to control the false discovery rate then we find that the left-handedness estimates for the cognitive development outcomes PIAT-M and PIAT-C are significantly different from 0 at the 5% level.

The conditional intraclass correlation estimates from the random-intercept models are given in the last panel of Table 3. They represent the level of correlation between children in the same family (family level) and between measurements on the same child (child level). The family level correlation is particularly high for behavioural problems (0.368), which is perhaps unsurprising given that child behaviour is strongly influenced by interactions with siblings and parents. The child level correlation is highest for reading recognition (PIAT-R) and behavioural problems but is relatively high for all the cognitive ability measures. The lowest intraclass correlations are for injuries (0.071 and 0.113), which presumably reflect the more random nature of accidents.

4.3. Handedness differences by gender and age

Previous studies have found that the left-handed differential in child outcomes is larger for boys than for girls (see, for example, Johnston *et al.* (2009) and Vuoksimaa *et al.* (2009)). To explore this possibility we re-estimate each of the models with interactions between each covariate and an indicator for male, and each covariate and an indicator for female. The resulting male and female handedness estimates are shown by row in Table 4. Row (1) indicates that left-handedness is not associated with an increased likelihood of illness for boys, but does significantly (but only

Table 4. Handedness effect estimates by gender from three-level random-intercept models†

	Estimates for males	*Estimates for females*	*Test of equality*	*Sample size*
Health				
(1) Illness	0.024	0.134‡	0.277	36837
	(0.065)	(0.077)		
(2) Injury	0.170§	−0.091	0.054	36837
	(0.078)	(0.111)		
(3) BPI	0.292	0.422	0.811	26841
	(0.350)	(0.411)		
Cognitive				
(4) PPVT	−0.895§	−0.263	0.254	13335
	(0.357)	(0.422)		
(5) PIAT-M	−0.704‡	−0.645	0.915	24119
	(0.363)	(0.429)		
(6) PIAT-R	−0.221	−0.263	0.944	24013
	(0.388)	(0.458)		
(7) PIAT-C	−0.824§	−0.727‡	0.864	20567
	(0.382)	(0.440)		

†Figures in rows (1) and (2) are coefficient estimates from logit models. All other figures are coefficients from linear models. Test of equality figures are p-values from a χ^2-test. Coefficient standard errors are presented in parentheses. Regressions include the same set of covariates as presented in Table 3, except that each covariate is interacted with gender binary variables.
‡Significance at the 0.10 level.
§Significance at the 0.05 level.

at the 10% level) increase the likelihood for girls requiring medical attention in the previous 12 months (computed odds ratio 1.143). For the injury outcome we find the opposite result. Left-handed boys are significantly more likely to have a serious injury than their right-handed counterparts (computed odds ratio 1.185), but no such difference is found for girls. Moreover, the p-value on the test of equality handedness estimate for injury between boys and girls is 0.054. For behavioural problems we find no evidence that being left handed is associated with more problems than being right handed.

The cognitive development results in rows (4)–(7) show that the negative effect of left-handedness is particularly large for boys. Left-handed boys score approximately 9% of a standard deviation lower in vocabulary, 7% of a standard deviation lower in mathematics and about 8% of a standard deviation lower in reading recognition than their right-handed counterparts. In contrast, for girls the left-handedness effect, although negative in sign for all measures, is significant only at the 10% level for reading comprehension (7% of a standard deviation). However, although the difference in the point estimates for PPVT between boys and girls (−0.895, −0.263) is large, they are not significantly different from one another; nor are they significantly different for mathematics, reading or comprehension.

We are also interested in investigating whether the handedness differences for health and cognitive development change as children grow older. As left-handed children grow older, do they catch up with their right-handed peers in terms of cognitive development or do they fall further behind? To investigate this issue we again re-estimate each model including full sets of interactions. In this instance we interact each covariate with variables indicating that the child

Table 5. Handedness effect estimates by age from three-level random-intercept models†

	Estimates for aged 5–9 years	*Estimates for aged 10–14 years*	*Test of equality*	*Sample size*
Health				
(1) Illness	0.056	0.106	0.636	25903
	(0.077)	(0.086)		
(2) Injury	−0.031	0.160	0.157	25903
	(0.101)	(0.098)		
(3) BPI	0.344	−0.072	0.142	24370
	(0.282)	(0.293)		
Cognitive				
(4) PIAT-M	−0.610‡	−0.716‡	0.704	24119
	(0.303)	(0.316)		
(5) PIAT-R	−0.116	−0.423	0.231	24013
	(0.317)	(0.328)		
(6) PIAT-C	−0.395	−1.166§	0.014	20567
	(0.336)	(0.326)		

†Figures in rows (1) and (2) are coefficient estimates from logit models. All other figures are coefficients from linear models. Test of equality figures are p-values from a χ^2-test. The estimation sample has been restricted to children aged 5–14 years. Coefficient standard errors are presented in parentheses. Regressions include the same set of covariates as presented in Table 3, except that each covariate is interacted with age group binary variables.
‡Significance at the 0.05 level.
§Significance at the 0.01 level.

is aged 5–9 years and that the child is aged 10–14 years. PPVT results are not provided as this information is collected only until age 11 years. The results are shown in Table 5. We find no significant evidence that the effect of handedness on the three health measures increases or decreases as children move into early adolescence, although the point estimates for both illness and injury increase with age. In terms of cognitive development we find that the gap between left- and right-handed children increases with age for mathematics, reading and comprehension, but this is only significantly different in the case of comprehension.

4.4. *Testing for robustness by using a sibling fixed effects model*

As a robustness test we have also fitted sibling fixed effects models where the handedness effect is estimated from differences in handedness, health and cognitive development between siblings in a particular year. This is a common alternative modelling strategy to the random-effects framework that we have used and, as Siedler (2011) explained, ‘a key advantage of sibling differences models is that observable and unobservable family-specific fixed effects are cancelled out’ (page 742). Ermisch *et al.* (2004) also includes a detailed discussion of the advantages and disadvantages of sibling differences models. Importantly, the results that are presented in Table 6 support the results from our main random-effects models. In particular, being left handed is associated with significantly lower test scores for vocabulary, mathematics and comprehension, and left-handed girls have a higher probability of illness, and left-handed boys have a higher probability of injury, than their right-handed counterparts.

Table 6. Fixed effect estimates of handedness effects†

	Estimates for all	*Estimates for males*	*Estimates for females*	*Estimates for aged 5–9 years*	*Estimates for aged 10–14 years*
Health					
(1) Illness	0.033	−0.038	0.226‡	0.082	0.104
	(0.073)	(0.093)	(0.115)	(0.139)	(0.149)
(2) Injury	0.127	0.252‡	−0.146	0.161	−0.046
	(0.096)	(0.119)	(0.168)	(0.176)	(0.182)
(3) BPI	−0.046	−0.094	−0.053	−0.058	−0.226
	(0.230)	(0.313)	(0.373)	(0.339)	(0.361)
Cognitive					
(4) PPVT	−0.794‡	−0.819	−0.325	—	—
	(0.394)	(0.569)	(0.628)		
(5) PIAT-M	−0.875§	−1.116§	−0.495	−0.987‡	−0.690
	(0.303)	(0.424)	(0.429)	(0.403)	(0.463)
(6) PIAT-R	−0.374	−0.829‡	0.306	−0.187	−0.589
	(0.300)	(0.414)	(0.426)	(0.386)	(0.470)
(7) PIAT-C	−1.240§	−1.204‡	−0.836§§	−0.359	−1.819§
	(0.354)	(0.492)	(0.493)	(0.488)	(0.471)

†Each row provides results from a separate fixed effect regression model. Rows (1) and (2) present coefficients from (conditional) logit models, and rows (3)–(7) present coefficients from linear models. Standard errors adjusted for intrafamily correlation (clustered) are presented in parentheses. Regressions include the same set of covariates as presented in Table 3.
‡Significance at the 0.05 level.
§Significance at the 0.01 level.
§§Significance at the 0.10 level.

5. Conclusion

In this paper, we focus on one particular factor that affects child outcomes and also a large number of people in any population, namely the difference in health and cognitive development between left- and right-handed children. We improve on existing studies in several ways but, most importantly, we use multilevel models that control for unobserved family characteristics, which might be important in determining child outcomes. We also test whether handedness differentials exist across a wider range of health and development indicators. To do this we use data drawn from the child supplement of the NLSY. Data from the NLSY are higher quality than the data that are used in the majority of existing studies, which often come from small cross-sectional surveys of non-random samples of children.

Left-handedness is often associated with some mental (e.g. depression and schizophrenia) and physical illnesses (e.g. asthma) among adults. However, our estimates provide no strong evidence that left-handed children are more likely to suffer from illness or injury, or experience behavioural problems, than right-handed children. The only evidence that we find of a handedness–health relationship during childhood occurs when we allow the effects of handedness to differ by gender. In this instance we find that left-handed girls have more illness than their right-handed counterparts (odds ratio 1.143), and that left-handed boys have more injuries than right-handed boys (odds ratio 1.185). The differences between genders, however, are only weakly significant and so we interpret these gender effects with some caution.

Turning to cognitive development, we find consistent evidence that left-handed children perform worse than right-handed children in all areas of development with the exception of reading. Quantitatively, the differences in development are important, with left-handed children scoring about 6% of a standard deviation lower in vocabulary tests, 7% lower in mathematics tests and 8% lower in comprehension tests than their right-handed siblings. No significant difference, however, was found for reading tests. Overall, the effect of hand preference on general cognitive ability confirms the results of studies such as Johnston *et al.* (2009), which also use a large representative sample of children.

Using kernel density estimates to examine the nature of the cognitive development effects, Johnston *et al.* (2009) found that the entire normal-shaped distribution for left-handers shifted towards lower scores compared with right-handers. Kernel density estimates in this current study reveal a slightly different picture. In this case, the differences emerge only for children in the far left-hand tail of the ability distribution, i.e. for children with below average cognitive ability scores. No differences for children with above average scores are found. The fact that the distributions are effectively identical for children with above average scores and that there is no sign of an excess of left-handed children with extremely high cognitive ability scores militates against the argument that some left-handers are gifted (Benbow, 1986). That said, giftedness may relate to some very specialized cognitive functions, which are not tapped by the general cognitive ability tests that were used in this study. The excess of left-handed children with very low cognitive ability scores suggests that there is a subgroup of left-handers who perform quite differently from other left-handers and who are considerably disadvantaged in their cognitive ability. It is noteworthy that this disadvantage relates quite specifically to cognitive functions and does not otherwise affect mental health.

We have also investigated whether health and cognitive development differences between left- and right-handed children increase or decrease with age. For five of the health and cognitive development measures we found point estimates that indicate larger handedness differentials for children aged 10–14 than 5–9 years. However, a lack of statistical significance, with the exception of the case of comprehension, does not allow us to make any firm conclusions. Given this lack of significant difference we tentatively suggest that the overall results favour a difference in brain functioning explanation for the handedness differentials, rather than an explanation based on left-handed children facing the difficulties of living in a world that is designed for right-handed people. If the cognitive disadvantage that is experienced by left-handed children were the result of environmental effects, such as problems interacting with a right-handed world, or social stigmatization, we might expect the differential to increase more strongly with age. Conversely, it could be that left-handers learn to cope better in a right-handed world as they become older, and that the disadvantage may diminish with age. Further work using larger samples, and following children into later adolescence and early adulthood, is needed to shed further light on this issue.

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