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ABSTRACT

Handedness, Health and Cognitive Development: Evidence from Children in the NLSY

Using data from the US National Longitudinal Survey of Youth, and fitting family fixed-effects models of child health and cognitive development, we test if left-handed children do significantly worse than their right-handed counterparts. The health measures cover both physical and mental health, and the cognitive development test scores span (1) Memory, (2) Vocabulary, (3) Mathematics, (4) Reading and (5) Comprehension. We find that while left-handed children have a significantly higher probability of suffering an injury needing medical attention, there is no difference in their experience of illness or poor mental health. We also 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, the left-handedness disadvantage is larger for boys than girls, and remains roughly constant as children grow older for most outcomes. We also find that the probability of a child being left-handed is not related to the socioeconomic characteristics of the family, such as income or maternal education. All these results tend to support a difference in brain functioning or neurological explanation for handedness differentials rather than one based on left-handed children living in a right-handed world.

JEL Classification: I12, J10

Keywords: handedness, children, health, cognitive development, family fixed-effects

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1. Introduction

Identifying the causal factors that influence child health and cognitive development are key tasks for social scientists, as childhood health and development strongly impact educational and adult outcomes. Consequently, there exists a vast inter-disciplinary literature that has examined a wide array of potential factors that affect child health and cognitive development (see, for example, Haveman and Wolfe, 1995; 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; James-Burdumy, 2005; and Ruhm, 2008), 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). While 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 under-researched aspect of child health and development, but one that affects a large group of individuals in any population. Our contribution is to better quantify the effect that handedness, being left-handed rather than right-handed, has on child health and cognitive development using panel data on US siblings across a variety of health and developmental measures. This is important, because left–right asymmetrical brain function underlies much of human cognition, behavior and emotion (Francks et al. 2007).[1] This is also a quantitatively important issue as there are currently around 31 million dominantly left-handed people in the US, or roughly 10 percent of the population, which is about the size of the population of California.[2]

A better understanding of the impact of handedness on child health and cognitive development, and whether handedness differentials change with age, will help to explain any observed educational and labor market differentials. Two recent papers have investigated the relationship between left-handedness and earnings (Denny and O'Sullivan, 2006; Ruebeck et al., 2007), although their results are mixed. Denny and O'Sullivan (2006) find that left-handed men in Britain earn approximately 5 percent

[1] See McManus (2002) and Harris (2003) for fascinating accounts of various aspects of the history of handedness, or brain asymmetry, going back to classical times. Llaurens et al. (2009) provide a detailed evolutionary perspective on why some people are left-handed. Steele (2000) provides an interesting account of the evidence from skeletal markers that right-handedness has predominated in human populations since at least the appearance of Homo sapiens.

[2] It has been found that the proportion of people who are left-handed equals 11 percent in Canada (Bryden et al., 1997), 12 percent in the U.S. (Ruebeck et al., 2007), and 12 percent in the U.K. (Denny and O'Sullivan, 2007). However, there is evidence of wider geographic variation in the prevalence of left-handedness, depending to a large extent on how handedness is measured and sampling (Llaurens et al., 2009).

more than right-handed men, and that this premium is slightly higher for non-manual workers. Yet they find 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 percent less per hour than their right-handed equivalents. Using US data, Ruebeck et al. (2007) also find 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 percent more than right-handed males. Unlike Denny and O'Sullivan (2006), however, they find no significant wage effect for women. Faurie et al. (2008) explore the relationship between socio-economic status and handedness in two cohorts of French data. They find only weak correlations between handedness, education and income, with left-handers being slightly over-represented in higher education level (only for females) and higher income groups.

In this study we use data from the US National Longitudinal Survey of Youth (NLSY), which enables us to improve on previous studies on handedness and child health and development outcomes in a number of important ways. Firstly, by observing siblings, and in particular utilizing families that have both left and right-handed children, we are able to control for family fixed effects in our estimations. As far as we know, this is the first paper that investigates the relationship between child handedness, health, and cognitive development, which controls for unobservable family heterogeneity. Secondly, since the data tracks children from birth to young adulthood, we are able to test whether the health or development differentials by handedness increase or decrease as children grow older. Thirdly, the NLSY contains information on whether the child's mother is left or right-handed, which allows us to establish the extent of the intergenerational transfer of handedness. Fourthly, 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 poor mental health.

2. Causes of handedness and their consequences for health, accidents and cognitive development

It quickly becomes apparent from reading the literature both on the causes and 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 reasonably compare studies (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 multi-disciplinary literature on the theories and empirics of handedness, we are only able to give a selected review, focusing on what we think are important studies.

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 while 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; Vuoksimaa et al., 2009; for reviews). Perhaps the most agreed upon finding is the strong genetic link for the intergenerational transfer of handedness. In particular, compared to 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 (see Francks et al., 2007). However, this link has been strongly contested (see Crow et al., 2007; 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 pre- or peri-natally 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) show 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) find that prenatal exposure to maternal depressive symptoms and critical life events are associated with increased risk of non-right-handedness. However, other studies find that pre- or peri-natal brain insult probably only account for a small proportion of left-handers (Satz et al., 1985). For example, Bailey and McKeever (2004) find that out of 25 potential ‘stressors’ only maternal age shows a significant relationship with left-handed offspring. Another exogenous factor proposes that prenatal exposure to androgens, such as testosterone 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 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). 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 percent, whereas in more conservative, formal cultures the incidence of left-handedness drops to 8.9 percent. However, while hand preference can be affected by social environment, it is unlikely that it is determined entirely by culture. If handedness is socially constructed, one might expect at least one culture where left-handedness predominates – and this does not appear to be the case. In addition, the fact that right-handedness has prevailed since prehistoric times, perhaps dating back to homo habilus 2.5m years ago (Toth, 1985) militates against a cultural explanation.

Handedness has been associated with a number of traits and outcomes during a person's lifetime. Amongst these, a large medical and psychological literature has developed theories and undertaken empirical work to understand if there is a relationship between handedness and health outcomes (see Bryden et al., 2005, for a review). While 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 papers in this area are Bishop (1986), Bryden et al. (1991), Coren and Halpern (1991), Coren (1994) and Bryden et al. (2005).

With regards 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. In a recent paper, Denny (2009) analyzing large population survey data from 12 European countries finds that left-handed adults are significantly more likely to experience depressive symptoms than right-handers. However, the evidence supporting increased schizophrenia amongst pathological left-handers has been mixed (see Green et al., 1989; 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) find an association between hand preference and epilepsy, heart disease, thyroid disorders, and allergies; though the samples used for the analysis are very small. Health problems such as these might lead to the reduced longevity for left-handers reported by Halpern and Coren (1988). However, the finding of a lower life expectancy among left-handers has not been supported by numerous other studies (see, for example, Ellis et al., 1998; Peto, 1994; Steenhuis et al., 2001; Berdel Martin and Barbosa Freitas, 2003).[3] 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 likely of being left-handed and a greater susceptibility of certain illnesses (see Geschwind and Behan, 1982, 1984; 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; Coren, 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 designed for right-handers. For example, Reio et al. (2004) find significant differences in various aspects of spatial ability, with 3-D rotation and speeded visual exploration slightly favoring left-handers, but spatial location memory favoring 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) finds that non-right-handers have a greater risk of bone breaks and fractures than right-handers, while Dutta and Mandal (2006) find that left-handers have more driving accidents, while right-handers have more sports accidents. However, Pekkarinen at al. (2003) analyzing a sample of about 8,500 men and women from Finland, find no significant difference in injury involvement between left- and right-handers. The finding is also supported by Merckelbach et al. (2006).

In terms of handedness and cognitive ability, there are also a number of 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; McManus, 2002) while conversely others predict lower abilities (Annett, 1985; Bakan et al., 1973; McManus and Mascie-Taylor, 1983; Resch et al., 1997). Annett (1985) proposes a genetic model of handedness which predicts lower cognitive abilities for left-handers. Evidence for a general cognitive disadvantage for non-right-handers compared to right-handers is reported by McManus and Mascie-Taylor (1983). Resch et al. (1997) also report lower levels of achievement in left-handers in spelling, educational success and non-verbal intelligence. Johnston et al. (2009) find that left-handed Australian

[3] The major problem with the idea that left handed individuals live shorter life spans is that older people grew up in a different educational regime and older people are less likely to be left-handed because they were often forced to use their right hand at school i.e. the 'modification hypothesis'. Subsequent studies which took this "switching" into account found a much reduced, if any, longevity differential by handedness.

children do significantly worse in nearly all measures of child development, with the relative disadvantage being larger for boys than girls. In contrast, Faurie et al. (2006) using a sample of children from French public schools, find only very weak correlation (0.1) between handedness and a single measure of student performance. Using a sample of 1,022 children aged 3 to 6, Dellatolas et al. (2003) also find that laterality is only weakly associated with children's cognitive ability. Vlachos and Bonoti (2004) find no significant differences in performance across four drawing-related tasks by handedness, although the study only used a sample of 182 children aged between 7 and 12.

In contrast to theories proposing that left-handers are generally disadvantaged relative to right-handers, McManus (2002) suggests that left-handedness bestows a cognitive advantage. This proposition is based on genetic theory where handedness is controlled by a gene with two alleles, one of which is dominant while the other is recessive. In this case, however, McManus argues that the recessive gene, which causes left-handedness, persists because it is cognitively advantageous. In support of a left-handed advantage, Benbow (1986) finds an excess of gifted children among individuals who are left-handed. Halpern et al. (1998) also find that left-handers have higher scores for verbal reasoning tests and are over-represented in the upper tail of the distribution. Conversely, Piro (1998) finds no difference in mean handedness scores between 657 gifted and non-gifted children. Similarly, Johnston et al. (2009) find 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

Data are from the National Longitudinal Survey of Youth (NLSY), a sample of 12,686 Americans who were 14-21 years old in January 1979. Respondents were first interviewed in 1979 and were re-interviewed annually from 1979 to 1994, and biennially from 1994 to 2006.[4] Importantly, in each even-numbered year since 1986 the NLSY collected detailed information, including health and cognitive development assessments, on all children born to and living with a female NLSY respondent. The NLSY cognitive development data have been widely used in a number of different literatures. For examples, see Argys et al. (1998), Guo and Harris (2000), James-Burdumy (2005), and Case and Paxson (2008).

In this paper, child handedness is determined by his/her mother's response to the question, "Which hand does child use for writing?" to which mothers could answer left, right or both. This question was

[4] The NLSY over-sampled blacks, Hispanics, low-income whites and military personnel. In our analysis, we have not excluded these over-samples; however, when the analysis is repeated using only the representative sample, very similar results are obtained.

asked in surveys between 1996 and 2006, and so children with multiple responses are allocated handedness based on their latest response (average age handedness is measured is 13). 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 percent of the children are left-handed, which corresponds with 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 too small for the family fixed-effect analysis to be reliably estimated.[5]

It is important to note that it could be the case 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. While we are not able to test for this possibility directly in our analyses, we believe that any such bias would likely 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 suggests 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 percent of the children replied yes.

Children’s health is measured using mother’s 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 two years for all children from birth to age 14, and so for each child we have on average 5.5 responses for each health measure. Across years, the estimated probability of reporting an illness is 34 percent and the estimated probability of reporting an injury is 10 percent.

Children’s mental health is assessed using the Behavior Problems Index (BPI). The BPI consists of a 28-item maternal questionnaire and measures the frequency and types of behavior problems manifested by children aged 4 to 14 in the past three months. Items include both internalizing behavioral problems, such as “child complains no one loves him/her” and externalizing behavioral 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 in order to form the BPI, which is increasing in behavioral 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 6 BPI measurements; however, the average number of measurements for our estimation sample is 4.1.

[5] Ninety-nine children (or 1.5 percent of the sample) are dropped due to mixed-handedness.

Child cognitive development is measured using the following five tests administered since 1986: i) 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; ii) PIAT of reading recognition, which assesses skills such as matching letters, naming names and reading single words aloud; iii) PIAT of reading comprehension, which assesses the child's ability to derive meaning from sentences that are read silently; iv) Peabody Picture Vocabulary Test (PPVT), which assesses receptive vocabulary for Standard American English and provides a quick estimate of verbal ability and scholastic aptitude; and v) Memory for Digit Span Test, which assesses short-term memory. 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 to 14, PPVT scores for children aged 3 to 11, and Digit Span Test scores for children aged between 7 to 11. These ages are based on the ages of the children the tests were mostly administered to. Children completed age-appropriate versions of the tests on a number of occasions, ranging from an average of 2 test scores for the memory test and an average of 3.8 test scores for the mathematics and reading tests. Since the five test types (memory, vocabulary, mathematics, reading and comprehension) have different scales, we rescale each score to have a mean of 100 and a standard deviation of 10.

The children are described by handedness in Table 1. Column 1 presents mean health and cognitive development outcomes, and mean child and family characteristics for all children who have non-missing handedness and non-missing outcome information.[6] Column 2 presents mean values for the subsample of children who have a surveyed sibling with different handedness than themself. The total number of children in the subsample equals 1392, with 548 left-handed children and 844 right-handed children. It is this subsample that identifies the handedness effect in our family fixed-effects models. Columns 3 and 4 present mean values for the sibling subsample split by handedness.

The table indicates that the sibling subsample is relatively similar to the full sample of children. The most notable covariate differences between samples exist in the number of siblings (unsurprisingly), black, caesarean section birth, maternal handedness and maternal hours worked. These are all characteristics that tend to be associated with larger families and with left-handedness in children. If we compare the sibling sample with the sample of families with at least two children, many of these sample differences are reduced. Mean illness rates and test scores are also lower for the sibling

[6] Children with missing information for the following key control variables are omitted from the sample: caesarean section birth, birth weight, premature birth, breastfed, drank during pregnancy, smoked during pregnancy, maternal education, and maternal AFQT score.

subsample than for the full sample, which can be explained by the differences in characteristics just outlined or by a direct negative effect of left-handedness on test scores. A comparison of columns 3 and 4 suggests that left-handed children have higher rates of illness and injury, and lower average scores for memory, mathematics, reading and comprehension, but higher average scores for vocabulary.

For the continuous BPI measure, Figure 1 shows the kernel density graphed separately for left and right-handed children. If anything, the graph suggests that left-handed children are more likely to be observed in the right-hand tail of the BPI distribution. The right hand graph of Figure 1 shows kernel densities of cognitive development and demonstrates a distinct difference in cognitive development between left- and right-handed children.[7] The left-handedness effect for cognitive development primarily shifts the density from the middle of the distribution to the left-hand tail, rather than shifting the whole distribution leftward. In other words, left-handedness increases the probability of some children being poorly developed. Interestingly, the right-hand tail of the left- and right-handed test score distributions are very similar, implying that we find no supportive evidence of 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. A comparison of columns 3 and 4 also reveal some handedness differentials in gender, birth weight and caesarean section birth. In the following section, we further investigate these differences between left- and right-handed children using regression analysis.

4. How is Handedness Determined?

We investigate the theories of handedness discussed in Section 2 by estimating a probit model of handedness. We include covariates such as age, race, number of siblings, whether the child was breastfed, maternal handedness, maternal education, maternal AFQT score, mother's age at birth, and household income. We also include indicators of a caesarean birth, premature birth, low birth weight, and drinking and smoking during pregnancy. We use this later set of variables as indicators of birth complications to test the Bakan et al. (1973) theory that some minor brain insult pre- or peri-natally causes a cognitive decline as well as a shift towards right hemisphere dominance leading to left-handedness. Within this framework, we can also investigate whether handedness is associated with

[7] The cognitive development measure used in Figure 1 is the mean of the three PIAT test scores: mathematics, reading recognition, reading comprehension. These tests are used because they are administered between the ages 5 to 14.

socioeconomic status (SES) since we have a measure of household income, maternal education and maternal labor supply. The presence of such an association has important ramifications, because if SES influences development outcomes, estimates of the impact of handedness on child development will be biased. For example, if right-handed children come from richer households, then right-handed children might be more developed, even in the absence of a causal effect of handedness on child development.

The marginal effects from the probit model of handedness are reported in Table 2. There are only a few variables that are significantly related to handedness. As expected, the strongest relationship is between maternal handedness and child left-handedness. Mothers who are left-handed are 5 percentage points more likely to have a left-handed child. These results confirm that handedness has a strong genetic component (Annett, 1985). In addition, as previously found, boys are more likely to be left-handed than girls. An interesting result, which has not been previously documented as far as we are aware, is that black children are significantly more likely to be left-handed than children of other races.

The low birth weight coefficient is positive and marginally significant (.10 level), providing some evidence in support of Bakan et al.'s (1973) theory that handedness is caused by birth stress. However, our other indicators of possible birth stress, premature birth, caesarean section birth, drinking during pregnancy and smoking during pregnancy, are not significantly different from zero, and so the evidence supporting the birth stress theory is weak at best. Importantly, household income does not impact handedness. This result, coupled with the statistically insignificant coefficients on maternal education, AFQT score and maternal labor supply suggests that handedness is not associated with SES. Overall, we can conclude that handedness in our sample is not strongly associated with birth complications or with observable differences in SES. This suggests that handedness can be potentially used to provide some exogenous variation in child outcomes that can be used for identification in empirical analyses (see Frijters et al., 2009, for an example).

5. Impact of Left-Handedness on Health and Cognitive Ability

We are interested in regressing child health and cognitive outcomes on handedness to understand how child handedness impacts child development. For child *i* in family *j* at age *t*, we assume that the development outcome is given by:

$$D_{ijt} = \alpha LH_i + \beta' XC_{it} + \delta' XF_j + \varepsilon_{ijt} \qquad (1)$$

where D_{ijt} is one of the three health outcomes or five test scores discussed in Section 3, LH_i is a binary variable representing child left-handedness, XC_{it} and XF_j are vectors of covariates, and ε_{ijt} is a random error term. The XC_{it} vector includes characteristics that vary across children in the same family (e.g. gender, age, number of siblings, low birth weight, premature birth, caesarean section birth, breastfed, mother's age at birth, mother's labor supply and whether mother smoked or drank during pregnancy). The XF_j vector includes family-level characteristics that are fixed across children (e.g. mother's handedness, race, mother's education and mother's AFQT score). The coefficient α is the parameter of primary interest and represents the impact that left-handedness has on health or cognitive development.

While our preferred estimates of the effect of handedness are going to be based on sibling fixed-effects models, we provide OLS estimates of child health and cognitive development using the entire sample, and the same sample of siblings that we will use for the fixed-effects models (where at least one combination of a left- and right-handed child in the same family is observed) in Table 3. Comparing the OLS results from these two samples with the fixed-effects results allows us to distinguish between the (1) effect of any sample selection and (2) that of family unobservable characteristics, in explaining the source of the difference between the OLS and fixed-effects results. As shown in Table 1 and discussed in Section 3, families with both left- and right-handed children are not a random sample of families, and so right-handers in such families are likely to differ from right-handers in other families, affecting estimated handedness effects. For example, if on average right-handed children with left-handed siblings have better outcomes than right-handed children without left-handed siblings, then OLS estimates using the full sample will be more positive than OLS estimates using the fixed-effects sample.

Importantly, there is no significant relationship between handedness and physical or mental health outcomes for either sample. Only for the fixed-effects sample do we find that left-handed children have a significantly higher probability of having a serious injury relative to right-handers. Interestingly, regardless of the sample, the OLS results provide consistent evidence of a left-handedness disadvantage in most aspects of cognitive development, although the size of these effects is larger for the sibling sample, especially for memory and comprehension. Moreover, these differentials by handedness are large, with left-handed children scoring between 6.5 and 14 percentage of a standard deviation lower on memory, between 5.5 and 7.8 percent lower on mathematics and between 5.2 and 10.2 percent lower on comprehension tests. While the coefficients are also negative on the vocabulary and reading tests, the results are not statistically significant.

Omitted variable bias caused by unobserved family characteristics may, however, taint these OLS estimates. Handedness is (in part) genetically determined and so left-handed children may grow-up in somewhat different environments than right-handed children. To control for this family heterogeneity we include many measures of family-background, such as maternal education and maternal handedness, in the OLS regressions; though the controls may partially purge the bias, they are unlikely to remove it completely.[8] We still might expect unobservable family characteristics (for example paternal handedness) to potentially bias the OLS results.

To control for unobservable heterogeneity between families, and to fully utilise the advantage of the NLSY data, we estimate regression models that include family fixed-effects. The fixed-effects estimator implicitly subtracts the average for all siblings in a given family from each child's value:

$$\begin{aligned}\left(D_{ijt}-D_j^*\right) &= \alpha\ \left(LH_i-LH_j^*\right)+\beta'\left(XC_{it}-XC_j^*\right)+\delta'\left(XF_j-XF_j^*\right)+\left(\varepsilon_{ijt}-\varepsilon_{ijt}^*\right)\\ &= \alpha\ \left(LH_i-LH_j^*\right)+\beta'\left(XC_{it}-XC_j^*\right)+\upsilon_{ijt}\end{aligned} \tag{2}$$

where asterisks indicate family average values. By subtracting the family mean values, the effects on α from time-invariant family characteristics (both observed and unobserved) are removed. This approach also implies that the handedness effect is identified from only those families with both left- and right-handed children (otherwise $LH_i - LH_j^* = 0$). We estimate Equation 2 for the health outcomes and each development test score, and the estimates are presented in Tables 4 and 5. All standard errors shown take account of the lack of independence across observations.

As with the OLS estimates, the family fixed-effects estimates of the impact of left-handedness on illness and BPI are not significantly different from zero. Left-handedness is, however, estimated to have a significantly positive effect on the probability of experiencing an injury: left-handed children are 1.8 percentage points more likely to have had an injury requiring medical attention in the past 12 months.[9] The 1.8 percentage point increase corresponds to an almost 20 percent increase in the probability (10% to 12%), which is very similar to the 1.6 percentage point difference found for the OLS model using the sibling sample.

[8] We are aware that many of the covariates used in the OLS regressions could be considered endogenous (especially income and maternal labor supply); however, we include them to soak up as much variation as possible. If we were to just regress the test scores on handedness our results are qualitatively similar, but each estimated handedness effect is more significantly negative.

[9] A deleterious left-handedness effect is also found if the conditional logit model is used instead of the linear fixed-effects model. In the former model, the logit coefficient equals 0.191 and has a *t*-statistic of 2.16.

Importantly, the family fixed-effects estimates of the impact of left-handedness on cognitive development also indicate a strong significant negative relationship. Again, the estimates from these models are very close to those from the OLS models based on the sibling sample except in the case of vocabulary. Table 5 indicates that left-handed children score approximately 13 percent of a standard deviation (note that the standard deviation for each test score is equal to 10) lower on memory tests, 7 percent of a standard deviation lower on vocabulary tests, 9 percent of a standard deviation lower on mathematics tests and about 11 percent of a standard deviation lower on comprehension tests. These results are all statistically significant at the .01 or .05 percent level. While the coefficient on reading is negative, it is not statistically significant. These results are consistent with the findings of Johnston et al. (2009) using a large sample of Australian children. Interestingly, the magnitude of these negative effects is roughly equivalent to the negative effects of premature birth (see the review by Bhutta et al., 2002). In other words, we find that left-handedness is as much a hindrance to child development as being prematurely born.

6. Handedness Differences by Gender and Age

Previous studies have found that the left-handed differential in child outcomes is larger for boys than girls (see, for example, Johnston et al., 2009; Vuoksimaa et al., 2009). To explore this we re-estimate the family fixed effects models separately for boys and girls, which means that the handedness differential is identified by comparing brothers with brothers, and sisters with sisters, rather than looking at the difference in outcomes across all siblings. The results are shown in Table 6. While there are general differences in health outcomes by gender, we find that the relationship between handedness and accidents is significant only for boys. The cognitive development results also show that the left-handedness effect is particularly large for boys. In fact, all the coefficients for left-handed boys (Table 6) are larger than for the pooled sample (Table 5). For example, left-handed boys score 25 percent of a standard deviation lower on the memory test, 16 percent of a standard deviation lower on vocabulary, 20 percent of a standard deviation lower on mathematics, and 21 percent of a standard deviation lower on comprehension. The smallest difference between genders is found in memory and comprehension, with both left-handed boys and girls scoring significantly lower in these areas than their same-sex siblings. The largest difference between genders is found in vocabulary and mathematics. In these two areas left-handed boys perform significantly worse than their brothers, but in contrast left-handed girls perform only marginally worse than their sisters.

We are also interested in investigating whether the handedness differences for injuries and cognitive development change as children grow older. As left-handed children grow older, do they catch-up to their right-handed peers or do they fall further behind?[10] To investigate this issue we re-estimate the family fixed-effects regression models with age group-handedness interactions. We only provide these results for the outcome measures observed for the full age range. The results are shown in Table 7. Overall, these results suggest that the handedness differentials in cognitive development remain roughly constant as children grow older with the clear exception of injuries. For mathematics the handedness differential remains constant across the age groups, while no clear trend is observed for reading or comprehension. For injuries the difference between left- and right-handed children is largest and only significant for the oldest age group (aged 11-14). Younger left-handed children do not face a higher likelihood of injuries. We would tentatively suggest that the results tend to favor a difference in brain functioning explanation for these handedness differentials rather than (an increasing) one based on left-handed children facing the difficulties of living in a world designed for right-handed people. If the cognitive disadvantage suffered by left-handed children is the result of environmental effects, such as problems interacting with a right-handed world, or social stigmatization, one would expect the differential to increase more generally with age. The fact that it does not change with age, with the exception of injuries, suggests that the relationship between left-handedness and cognitive ability has a neurological origin.

7. 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 a number of ways, but most importantly, we fit family fixed-effects models that effectively control for unobserved family characteristics that might be important in determining child outcomes and which could bias the estimates. We are also able to test whether handedness differentials exist across a wider range of health and development indicators. To do this we use data drawn from the NLSY, which represents a considerable improvement over the majority of the existing literature, which is often based on small, cross-sectional, non-random samples of children.

[10] Van der Elst et al. (2008) found studying cognitive decline after the age of 50, no difference by handedness across speed of information processing, verbal learning, long-term verbal memory and executive functioning.

Left-handedness is often associated with a number of mental (e.g depression, schizophrenia) and physical (e.g. asthma) illnesses (Bryden et al., 2005, Denny, 2009, Nicholls et al., 2005) amongst adults. However, we find no evidence that in childhood left-handers experience more illness or worse mental health, suggesting that any differences arise in adulthood. We do find evidence that left-handed children have a significantly higher probability of experiencing an injury that requires medical attention. However, this difference is only significant for older children (aged 11-14), and this relationship is also larger for boys than for girls. The data for older children therefore reflects the results of adult studies, which also report an increased incidence of accidents in left-handers (Porac and Coren, 1981). Because this effect is observed for left-handed children, it rules out the possibility that the increased accident rate is only caused by adult activities related to driving and the work place. Whether the increased incidence of accidents for older children is caused by a child's interaction with his or her 'right-handed' environment or an increased level of clumsiness remains to be determined.

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 large, with left-handed children scoring about 13 percent of a standard deviation lower test scores in the memory test, 11 percent lower in comprehension, 9 percent lower in mathematics, and 7 percent lower in vocabulary. The size of these handedness differentials is about the same as found by comparing children who are born prematurely to those born with a normal gestation length. This 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 Australian children. Using kernel density functions to examine the nature of the distribution, Johnston et al. (2009) find that the entire bell-shaped distribution for left-handers shifted towards lower scores compared to the right-handers. Kernel density functions in this current study reveal a slightly different picture. In this case, the differences emerge for children with below-average cognitive ability scores, but there are no differences for children with above-average scores. 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 used in this study. The excess of left-handed children with very low cognitive ability scores suggests that there is a sub-group of left-handers who perform quite differently to 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.

Like many studies, we find that boys are more likely to be left-handed than girls. More importantly, we find that the handedness differential in cognitive development is larger for boys than for girls. This sex differential is also observed by Johnston et al (2009) for a large representative sample of Australian children. It is unclear why hand preference interacts with sex. It is possible however that handedness and sex operate in some additive manner whereby the brain mechanisms that bring about left-handedness are exacerbated by male physiology, such as increased androgen levels.

We also find that the differential in development by handedness remains roughly constant as children grow older for most aspects of cognitive development. Although very difficult to fully untangle, our results suggest an endogenous causal mechanism. If the cognitive disadvantage suffered by left-handed children is the result of environmental effects, such as problems interacting with a right-handed world, or social stigmatization, one would expect the differential to increase with age. The fact that it does not change with age suggests that the relationship between left-handedness and cognitive ability has a neurological origin. The data also demonstrate that left-handed children do not come from problematic births or pregnancies (with the exception of a slightly lower birth weight). It therefore seems unlikely that the association between left-handedness and reduced cognitive ability is caused by sub-optimal brain conditions either pre- or prenatally (Bakan et al., 1973). We are therefore left with the conclusion that the association is congenital. The shift in the dominance of the left hemisphere for the control of the right hand to dominance of the right hemisphere, which controls the left hand, may have a number of knock-on effects. One such effect is a reorganization of functions and their location in the brain, perhaps causing a sub-optimal 'crowding' of cognitive functions in certain brain regions (Levy, 1976). More research is needed to determine whether these early life handedness development differentials pass through to different adult labor market outcomes and in particular whether or not left-handed youth are likely to chose different educational or career paths than their right-handed peers.

Finally, we find that the probability of a child being left-handed is a significant function of mother's left-handedness, but importantly it is not related to observable socioeconomic characteristics including family income or maternal education. It therefore can be potentially used to provide some exogenous variation in child outcomes that may be used for identification in empirical analyses.

Overall, given that left-handed children account for about 10 percent of the child population, we believe that studies of child development should take into account the importance of handedness, and that policy-makers in health and education should be aware of these handedness differentials when examining inequalities in outcomes.

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Figure 1:
Kernel Density of BPI and Test Scores for Right (solid) and Left (dashed) Handed Children

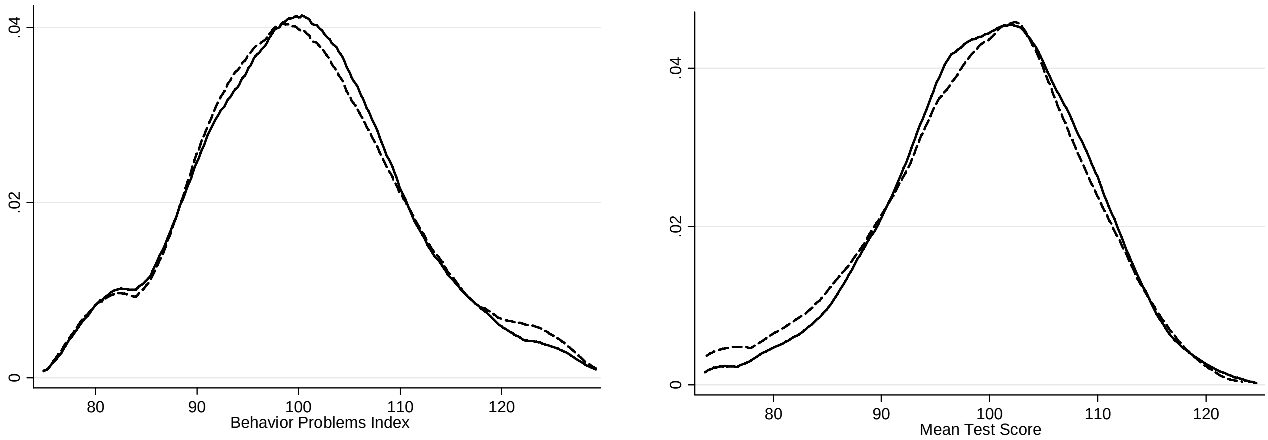

Table 1:
Health Outcomes and Development Test Scores and Characteristics for the Children from the NLSY79

		Sibling Sample		
	All	**All**	**Right-handed**	**Left-handed**
Health Outcomes				
Illness	0.342	0.316	0.305	0.333
Injury	0.104	0.102	0.093	0.115
Behavior Problems Index (BPI)	100.0	100.3	100.3	100.4
Development Test Scores				
Memory (Digit Span)	100.0	99.74	100.3	98.93
Vocabulary (PPVT)	100.0	98.83	98.76	98.94
Mathematics (PIAT-M)	100.0	99.01	99.12	98.84
Reading (PIAT-R)	100.0	99.12	99.17	99.04
Comprehension (PIAT-C)	100.0	98.88	99.09	98.55
Covariates				
Male	0.508	0.517	0.470	0.589
Age	7.396	7.403	7.425	7.370
Number of siblings	2.168	2.564	2.649	2.432
Mother's age at birth	25.64	25.54	25.46	25.670
Low birth weight	0.080	0.098	0.089	0.111
Premature birth	0.122	0.132	0.128	0.139
Caesarean section birth	0.224	0.185	0.168	0.212
Breastfed	0.459	0.428	0.428	0.429
Drinking during pregnancy	0.308	0.310	0.305	0.319
Smoking during pregnancy	0.262	0.267	0.286	0.237
Log income	8.842	8.596	8.546	8.675
Black	0.323	0.381	0.386	0.372
Hispanic	0.212	0.194	0.193	0.195
Mother left-handed	0.095	0.137	0.137	0.137
Mother mixed-handed	0.011	0.019	0.018	0.020
Mother's years of education	12.32	12.06	11.95	12.232
Mother's AFQT percentile	0.373	0.352	0.342	0.367
Mother hours worked	0.863	0.738	0.716	0.772
Number of Children	6534	1392	844	548

Notes: All columns include only those children who have handedness information and some test score and/or behavior problems index information. Sibling sample includes only those children who have a sibling with different handedness than themselves. Mean health outcomes and mean test scores are averages across both children and time. Covariate means, apart from age, are averages across children only. Mother hours worked equals total number of hours worked in first 2 years after birth divided by 1000.

Table 2:
Probit Model of Handedness

	Marginal Effects	**Std. Errors**
Male	0.035***	(0.007)
Age handedness measured	0.001	(0.002)
Number of siblings	0.004	(0.004)
Mother's age at birth	0.002*	(0.001)
Low birth weight	0.029*	(0.017)
Premature birth	0.005	(0.013)
Caesarean section birth	0.004	(0.009)
Breastfed	-0.015*	(0.008)
Drinking during pregnancy	0.011	(0.009)
Smoking during pregnancy	-0.012	(0.009)
Log household income	-0.000	(0.005)
Black	0.027**	(0.011)
Hispanic	-0.003	(0.011)
Mother left-handed	0.050***	(0.015)
Mother mixed-handed	0.074*	(0.046)
Mother's years of education	-0.001	(0.002)
Mothers AFQT percentile	0.024	(0.020)
Mother hours worked	-0.001	(0.003)
Sample size	6534	
Pseudo R-squared	0.016	

Notes: Probit marginal effects calculated using mean covariate values. Sample includes all children who have handedness information and some test score and/or behavior problems index information. Year dummies and a dummy for missing maternal handedness information (0.99% of the sample) are included in the model but not shown. *, ** and *** denote significance at .10, .05 and .01 levels. Mother hours worked equals total number of hours worked in first 2 years after birth divided by 1000.

Table 3:
OLS Estimates of Left-Handedness Effect on Health Outcomes and Test Scores

	Full Sample		Sibling Subsample	
	Estimated Effect	Obs.	Estimated Effect	Obs.
Illness	0.012	35776	0.016	7717
	(0.010)		(0.011)	
Injury	0.006	35776	0.016**	7717
	(0.006)		(0.008)	
BPI	0.287	26983	0.217	5799
	(0.331)		(0.340)	
Memory (Digit Span)	-0.653*	12170	-1.399***	2623
	(0.392)		(0.495)	
Vocabulary (PPVT)	-0.485	13421	-0.550	2893
	(0.304)		(0.358)	
Mathematic(PIAT-M)	-0.549*	24245	-0.783**	5274
	(0.315)		(0.384)	
Reading (PIAT-R)	0.024	24142	-0.418	5257
	(0.319)		(0.397)	
Comprehension (PIAT-C)	-0.520*	20679	-1.015***	4468
	(0.288)		(0.353)	

Notes: Estimated effects are OLS coefficients on left-handedness. Clustered standard errors in parentheses. *, ** and *** denote significance at .10, .05 and .01 levels. Set of control variables includes all those presented in Table 2.

Table 4:
Family Fixed-Effect Estimates of Left-Handedness Effect on Health Outcomes

	Illness	**Injury**	**BPI**
Left-handed	0.012	0.018**	0.269
	(0.011)	(0.008)	(0.292)
Male	-0.003	0.038***	-0.709**
	(0.012)	(0.010)	(0.321)
Age	-0.032***	0.003	0.350
	(0.005)	(0.003)	(0.217)
Age squared	0.001***	-0.000	-0.016
	(0.000)	(0.000)	(0.012)
Number of siblings	-0.037***	-0.005	0.114
	(0.008)	(0.005)	(0.226)
Mother's age at birth	-0.003*	-0.002	-0.247***
	(0.002)	(0.001)	(0.045)
Low birth weight	0.025	-0.005	-0.434
	(0.026)	(0.019)	(0.666)
Premature birth	0.010	-0.008	1.094
	(0.024)	(0.019)	(0.666)
Caesarean section birth	0.019	0.000	0.411
	(0.028)	(0.018)	(0.707)
Breastfed	0.008	-0.007	0.542
	(0.023)	(0.019)	(0.586)
Drinking during pregnancy	-0.013	-0.034**	-0.085
	(0.017)	(0.015)	(0.464)
Smoking during pregnancy	-0.015	-0.004	0.308
	(0.030)	(0.020)	(0.735)
Mother hours worked	-0.000	0.005	-0.381**
	(0.005)	(0.004)	(0.180)
Sample size	7717	7717	5799
R-Squared	0.044	0.005	0.041

Notes: Clustered standard errors in parentheses. *, ** and *** denote significance at .10, .05 and .01 levels. Sample includes only those children who have an observed sibling with different handedness than themselves. Mother hours worked equals total number of hours worked in first 2 years after birth divided by 1000.

Table 5:
Family Fixed-Effect Estimates of Left-Handedness Effect on Development Test Scores

	Memory (Digit Span)	**Vocabulary (PPVT)**	**Mathematic (PIAT-M)**	**Reading (PIAT-R)**	**Comprehension (PIAT-C)**
Left-handed	-1.324***	-0.690**	-0.859**	-0.566	-1.108***
	(0.488)	(0.348)	(0.375)	(0.401)	(0.363)
Male	-0.389	-0.032	0.877**	-1.534***	-0.926**
	(0.547)	(0.393)	(0.436)	(0.432)	(0.415)
Age	-8.652***	1.361***	1.876***	-0.475	-3.214***
	(2.016)	(0.307)	(0.305)	(0.295)	(0.362)
Age squared	0.482***	-0.056***	-0.097***	0.012	0.103***
	(0.112)	(0.020)	(0.016)	(0.015)	(0.018)
Number of siblings	0.262	-0.485*	-0.362	-0.597**	-0.283
	(0.310)	(0.276)	(0.230)	(0.295)	(0.207)
Mother’s age at birth	-0.000	-0.111*	0.042	-0.062	-0.158***
	(0.077)	(0.062)	(0.056)	(0.062)	(0.053)
Low birth weight	0.744	0.502	0.664	0.451	0.398
	(1.155)	(0.814)	(0.871)	(0.948)	(0.964)
Premature birth	-2.276*	-1.027	-1.700**	-1.182	-1.035
	(1.188)	(0.705)	(0.848)	(0.866)	(0.799)
Caesarean section birth	-0.296	0.328	-1.468	-0.462	-1.714*
	(1.415)	(1.255)	(1.109)	(1.070)	(1.028)
Breastfed	0.710	0.272	-0.042	1.070	0.717
	(0.961)	(0.715)	(0.695)	(0.761)	(0.636)
Drinking during pregnancy	0.073	-0.306	-0.463	-1.131**	-1.498***
	(0.790)	(0.569)	(0.583)	(0.570)	(0.530)
Smoking during pregnancy	-0.148	0.360	0.560	0.116	0.504
	(1.230)	(0.984)	(0.905)	(1.073)	(0.919)
Mother hours worked	0.214	0.187	0.296*	0.167	-0.017
	(0.264)	(0.179)	(0.176)	(0.180)	(0.160)
Sample size	2623	2893	5274	5257	4468
R-Squared	0.017	0.025	0.034	0.054	0.118

Note: Clustered standard errors in parentheses. *, ** and *** denote significance at .10, .05 and .01 levels. Sample includes only those children who have an observed sibling with different handedness than themselves. Mother hours worked equals total number of hours worked in first 2 years after birth divided by 1000.

Table 6:
Family Fixed-Effect Estimates of Left-Handedness Effect by Gender

	Males		Females	
Health Outcomes				
Illness	-0.011	(0.018)	0.033	(0.021)
Injury	0.023*	(0.014)	-0.012	(0.012)
BPI	0.368	(0.502)	0.286	(0.617)
Development Test Scores				
Memory (Digit Span)	-2.491***	(0.844)	-2.076**	(0.887)
Vocabulary (PPVT)	-1.621**	(0.689)	-0.793	(0.665)
Mathematics (PIAT-M)	-2.048***	(0.727)	-0.612	(0.645)
Reading (PIAT-R)	-1.122	(0.773)	-0.463	(0.646)
Comprehension (PIAT-C)	-2.063***	(0.675)	-1.727***	(0.602)

Notes: Figures are estimated effect of Left-handedness from separate fixed-effect regression models. Clustered standard errors in parentheses. *, ** and *** denote significance at .10, .05 and .01 levels. Regressions include the same set of controls as presented in Tables 4 and 5. Sample includes only those children who have an observed sibling with different handedness than themselves.

Table 7:
Family Fixed-Effect Estimates of Handedness Effect by Age Group

	Aged 5-7	Aged 8-10	Aged 11-14
Health Outcomes			
Illness	0.026	0.018	-0.008
	(0.021)	(0.021)	(0.021)
Injury	0.016	-0.001	0.040**
	(0.015)	(0.015)	(0.016)
BPI	0.565	0.319	-0.298
	(0.414)	(0.427)	(0.410)
Development Test Scores			
Mathematics (PIAT-M)	-0.844*	-0.845*	-0.894*
	(0.460)	(0.498)	(0.467)
Reading (PIAT-R)	-0.367	-0.843*	-0.481
	(0.445)	(0.475)	(0.544)
Comprehension (PIAT-C)	-0.747	-1.437***	-1.023**
	(0.488)	(0.486)	(0.458)

Notes: Figures are estimated coefficients on age-handedness interaction terms. Clustered standard errors in parentheses. *, ** and *** denote significance at .10, .05 and .01 levels. Regressions include the same set of controls as presented in Tables 4 and 5. Samples includes only those children who have an observed sibling with different handedness than themselves. Sample sizes for illness, injury and BPI are 5371, 5371 and 5251. Sample sizes for test scores are as given in Table 5.