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Sinistrality is associated with (slightly) lower general intelligence: A data synthesis and consideration of the secular trend in handedness

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A R T I C L E I N F O

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A B S T R A C T

The relationship between the general factor of intelligence (*g*) and handedness is investigated using a combined sample of 23511 respondents from three large databases: the NLSY'79 (US), NLSY'97 (US) and NCDS (UK). Dextrals – those who use their right hands were found to be 1.22 IQ points higher than sinistrals (left handers) after controlling for sex and age and correcting for sources of measurement error. To see if the association between IQ and handedness was strongest on the abilities that were the best measures of *g*, the method of correlated vectors was used to test for moderation. Across the three studies, *g* was found to very weakly negatively moderate the association between ability measure and handedness ($\rho = -.023$, $K = 3$, $N = 23511$), however in the NLSY'79, the coding speed subtest was an outlier in terms of the strength of its association with handedness. Its removal yielded indications of positive moderation in this dataset, which when aggregated boosted the overall vector correlation value to .539 ($K = 3$, $N = 23511$), suggesting that *g* might be an important moderator of this relationship. Secondary analysis of secular trend data on the changing percentage of sinistrals in Western populations indicates that overall, sinistrality has increased, entailing a *g* decline of .106 points over 150 years (.006 points per decade). The secular increase in sinistrality is consistent with other data indicating long-term declines in developmental stability and may stem from some combination of increasing mutation load and environmental stress in Western populations.

Introduction

The relationship between hand-preference and cognitive ability has led to intriguing findings. Early research indicated that left-handers (sinistrals) might be overrepresented among those with above average scores on specific measures of cognitive ability (Benbow, 1986; Halpern et al., 1998), however a consistent pattern is emerging across studies employing large samples and measures of general intelligence (*g*) indicating that sinistrals are at a very mild cognitive disadvantage relative to right-handers (dextrals) (Goodman, 2014; Johnston et al., 2013; Nicholls et al., 2010), and that this furthermore translates into real-world differences

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between the groups in terms of factors like earnings (Goodman, 2014).

One theory, first proposed by Markow (1992), is that sinistrality results from reduced developmental stability – the ability of an organism to buffer its development against environmental or genetic disturbances which it experiences during development such that it can produce a predetermined phenotype. Sub-optimal genetics (i.e. deleterious mutations) and environments (i.e. sources of ecological stress, such as pollution, parasites etc.) will cause development to deviate away from the optimum, leading to instability, and potentially pathological outcomes (Nijhout and Davidowitz, 2003; Waddington, 1942).

Developmental stability is a highly general property of an organism's phenotype, as deleterious mutations and environmental stress will affect multiple aspects of an organism's development in paralell, creating genetic and phenotypic correlations among them (Penke et al., 2007). Developmental stability is therefore likely to be very strongly related to underlying genetic quality (as an index of the load of deleterious mutations), which in turn indicates evolutionary fitness. Features of an organism that reliably indicate its condition therefore serve as honest signals of fitness on which sexual selection can operate. Examples include physical attractiveness – symmetrical faces are regarded as attractive because they evidence the ability to maintain a symmetrical phenotype in the face of environmental stressors and thus low mutational load – or simply health (Woodley of Menie & Kanazawa, 2017).

Consistent with this model, elevated rates of sinistrality are associated with several potential indica tors of developmental instability, including autism (Soper et al., 1986), schizophrenia (Dragovic and Hammond, 2005), immunological disorders (Geschwind and Behan, 1982), psychosexual disorders such as sexual fetishes (Rahman et al., 2007) and paedophilia (Fazio et al., 2014); reduced life expectancy (Marks and Williamson, 1991) and low birth weight (Searleman et al., 1989). Some studies indicate that advanced parental (specifically maternal) age might be a risk factor for sinistrality (Coren, 1990; Medland et al., 2009; Vuoksimaa et al., 2009). Advanced parental age increases the risk of new mutations in the offspring (Kong et al., 2012; Wong et al., 2016), and in the case of mothers, there may be an additional effect stemming from the degree of stress experienced by the developing foetus (Coren, 1990). Sinistrality may result specifically when damage occurs to the left cerebral hemisphere, causing lateralization (i.e. transfer) of various specialized neurological functions into the opposing hemisphere (Satz et al., 1985).

Small to modest magnitude relationships exist between *g* and measures of developmental stability (i.e. fluctuating asymmetry – individual differences in the degree of random variation between bilateral markers, such as eyes, ears, finger lengths etc.) (Banks et al., 2010; *cf*. Woodley of Menie and Fernandes, 2016). The existence of this developmental stability *nexus* may therefore account for the small-magnitude association between handedness and *g*.

It has also been found that the prevalence of sinistrality has been increasing for over a century (McManus et al., 2010). A very large meta-analytic study revealed that the prevalence appears to have decreased between 1830 and 1900 (from around 6% to 3% of the population), however a relatively much larger increase in the prevalence occurred between 1900 and 1980 (from around 3% to 12% of the population). The overall increase in the percentage of sinistrals is consistent with data indicating that developmental stability has likely been declining for over a century in Western populations (Rühli and Henneberg, 2013). Several indicators are consistent with this, including elevated rates of craniofacial fluctuating asymmetry (Kimmerle and Jantz, 2006; *cf*. Woodley of Menie and Fernandes, 2016), the increasing incidence of various medical abnormalities (Rühli and Henneberg, 2013) in addition to more recent increases in the prevalence of certain neurodevelopmental disorders, such as autism (Center for Disease Control, 2012) and Attention Deficit/Hyperactivity Disorder (ADHD) (Center for Disease Control, 2010). Consistent with this inference, the trend in sinistrality was found to exhibit a high-loading ($\lambda = .926$) on a chronometric factor tracking secular trends with respect to various 'somatic modifications', likely stemming in part from declining developmental stability (Woodley of Menie et al., 2017).

The general decline in developmental stability likely has two causes; the first is the increase in deleterious mutations, resulting from the severe relaxation of purifying selection operating on (especially Western) populations, possibly starting as long ago as 40,000 ybp. (Aris-Brosuo, 2018), and accelerating substantially at the beginning of the late modern era (Volk and Atkinson, 2008; Rühli and Henneberg, 2013; Woodley of Menie et al., 2018). Prior to the Industrial Revolution, around 50% of people born died before they reached adulthood, meaning that those likely to have fewer deleterious mutations – survived. With medical and technological advances, around 99% of children in developed countries now reach adulthood (Volk and Atkinson, 2008), with concomitantly significantly reduced opportunity for purifying selection to act on these populations (Rühli and Henneberg, 2013). It has been predicted that in industrialized countries, these accumulating mutations may be reducing fitness by between 1% and 5% per generation (Lynch, 2010; Lynch, 2016). Another potential source is pollutants stemming from industry (such as heavy metals, PCBs, dioxins etc), which may complement the effect of unpurified mutations by further reducing developmental stability (Demeneix, 2014).

Several lines of evidence now indicate that *g* has undergone secular declines in Western populations (see Woodley of Menie et al., 2017 for an overview), and that the Flynn effect (the apparent increase in IQ of three points per decade) is restricted to increasing specialization with respect to narrow abilities (Pietschnig and Voracek, 2015; te Nijenhuis and van der Flier, 2013). Based on a reanalysis of secular trend data on craniofacial fluctuating asymmetry, the contribution of decreasing developmental stability to declining *g* has been estimated to be small at −.16 points per decade (Woodley of Menie and Fernandes, 2016). The overall predicted decline in *g* appears to be larger however (−1.21 points per decade), as it includes losses due to genetic selection coupled with faster generational turnover among those with lower *g* (−.87 points per decade) and replacement migration (−.25 points per decade) (Woodley of Menie et al., 2017). The increase in the prevalence of sinistrality could be used in order to provide an additional indication of secular *g* decline due to increasing developmental stability.

Several parameters must be determined first however. These include the magnitude of the group difference between sinistrals and dextrals in terms of *g*, and whether or not the group differences are biggest when the *g* loading of abilities is greatest. Studies employing the method of correlated vectors (MCV) have found positive correlations between the *g* loadings of subtests and the strength of their association with fluctuating asymmetry, indicating that the largest association between cognitive ability and fluctuating asymmetry is at the level of *g* (Prokosch et al., 2005; Yeo et al., 2016). This relationship could be tested using data on handedness and cognitive ability. As a potential measure of developmental stability, handedness-ability correlations might be expected to exhibit a similar positive association with subtest *g* loadings.

Method

Estimating the association between handedness and g

In the first analysis, the association between handedness and *g* will be investigated in three large, population-representative cohorts. The first two are the National Longitudinal Survey of Youth (NLSY) 79 and 97 cohorts, which are representative of the US population. In NLSY'79, the participants were all aged between 14 and 22 at the inception of the study in 1979, and in NLSY'97, the participants were aged between 12 and 16 when the study began in 1997. The Armed Services Vocational Aptitude Battery (ASVAB) was administered to both sets of cohorts (1980 in the case of NLSY'79 and 1997–98 in the case of NLSY'97). The Armed Services Vocational Aptitude Battery (ASVAB), as administered to the NLSY'79 cohort includes five academic tests (Science, Arithmetic, Word Knowledge, Paragraph Comprehension, Mathematics Knowledge), three vocational tests (Auto & Shop Info, Mechanical Comprehension, Electronics Info), and two speeded tests (Numerical Operations, Coding Speed). A computer-adaptive form of the ASVAB (CAT-ASVAB) was administered to the NLSY'97 cohort. This ASVAB-variant split the Auto-Shop Information subtest into Auto Info and Shop Info respectively, and added an Assembling Objects subtest.

The handedness question was administered to the NLSY'79 respondents in 1993 and consisted of the following question: "*Were you born naturally left-handed or right-handed?*". The question administered to the NLSY'97 respondents in 2001 and 2002 was "*Are you left-handed or right-handed?*". A total of 8399 NLSY'79 respondents possessed data on all variables, whereas 6112 NLSY'97 respondents possessed data on all variables. Ambidextrous and unsure individuals were excluded from the analysis. Left-handedness can be understood as a spectrum ranging from those who do everything with their left hand to those who merely write with it. A more nuanced question would obviously have been preferable but currently these are the best available data.

A third dataset comes from the UK National Child Development Survey (NCDS), which is a prospective longitudinal study that has tracked a single population (born in Britain during the week of 03–09 March, 1958) for more than half a century. The respondents were interviewed in eight sweeps (Sweep 1 = age 7 to Sweep 8 = age 50–51). Various cognitive ability measures were administered to NCDS respondents at ages 7 (Sweep 1), 11 (Sweep 2), and 16 (Sweep 3). At Age 7, the respondents took four tests: the Copying Designs Test, the Draw-a-Man Test, the Southgate Group Reading Test and the Problem Arithmetic Test. At Age 11, they took a further five tests: the Verbal General Ability Test, the Nonverbal General Ability Test, the Reading Comprehension Test, the Mathematical Test, and the Copying Designs Test. At Age 16, they took two additional cognitive tests: the Reading Comprehension Test and the Mathematics Comprehension Test.

The handedness question employed in the current study was administered to Sweep 3 (age 16; the oldest cohort reporting these data was used in preference to younger ones, as hand preference 'crystallizes' in adolescence) where each respondent was asked to identify their best writing hand. 8990 respondents possessed data on all variables. As with the NLSY cohorts, ambidextrous and unsure individuals were excluded from the analysis.

Control of confounds

Age and sex are known confounds in studies investigating the association between handedness and cognitive ability, as lateralization differences have been noted between older and younger cohorts (consistent with the secular trend towards greater numbers of sinistrals) and between the sexes (e.g. Johnston et al., 2013). In order to control for these in estimating the relationship between handedness and *g*, a hierarchical general linear model (implemented in SPSS v.21 and using Type 1 Sum of Squares) will be used to determine whether there is a main effect of handedness (scored 0 for sinistrality and 1 for dextrality) on *g* after controlling first for sex and then for respondent age. All handedness-cognitive ability associations are controlled for these confounds.

Measurement error corrections

The handedness-*g* relationship is attenuated by measurement error (Hunter and Schmidt, 2004). Two sources of measurement error can be corrected – the reliability of the *g* factor score and the imperfect psychometric validity of *g* (i.e. the degree to which the *g* score derived from one study imperfectly measures the true construct *g*). The former can be corrected using Cronbach's alpha (an index of measure reliability; Cronbach and Shavelson, 2004, p. 400). For the latter, Jensen (1998, p. 383) suggests a conservative value of .9. Division of the regression coefficient by the square root of the reliability coefficient and then by .9 yields the reliability- and validity-corrected regression coefficient. By rescaling the *g* measure using a mean of 100 and a standard deviation of 15, the unstandardized regression parameter (*b*) can be used to directly determine the magnitude of the group difference in *g* between sinistrals and dextrals. These *b* values can also be corrected for measurement error in the same way as the regression coefficients in order to determine the 'true' magnitude of the group difference in *g*.

Aggregation

In order to determine the aggregate group difference between sinistrals and dextrals, a sample-size weighted correlation will be computed using the measurement error corrected *r* values computed for each dataset. 80% confidence intervals (CI) and heterogeneity statistics (I^2), which can be used to estimate between study variation, will also be computed.

Vector correlations

The method of correlated vectors (MCV) employs the correlation between a vector comprised of subtest *g*-loadings and a vector comprised of correlations or group-difference magnitudes associated with each of those subtests to determine the degree to which the *g* loading moderates the magnitude of the latter (Jensen, 1998). Biological effects, such as subtest heritabilities (Voronin et al., 2016), so-called "dysgenic" selection (Woodley of Menie et al., 2017) and inbreeding depression (Rushton and Jensen, 2010) are typically bigger when estimated using more *g*-loaded subtests, yielding positive vector correlations – a phenomenon termed the Jensen effect (Rushton, 1998). Influences on cognitive ability stemming from environmental or cultural sources, such as IQ gains accrued due to educational interventions (te Nijenhuis et al., 2014), adoption of lower ability children into higher ability families (te Nijenhuis et al., 2015) and the Flynn effect (te Nijenhuis and van der Flier, 2013) tend to be bigger when the ability is less *g*-loaded – this being the anti-Jensen effect.

As fluctuating asymmetry (a biological measure of developmental stability) has been found to exhibit a Jensen effect (Prokosch et al., 2005; Yeo et al., 2016), it is predicted that handedness should also be associated with the Jensen effect, if it is also an indicator of developmental stability. This can be tested using vectors of *g* and of sinistral-dextral ability differences (*b*) computed for each subtest from each battery separately.

Various sources of measurement error attenuate the results of studies using MCV – range restriction among the *g* loadings, reliability of the column vector of *g* loadings, reliability of the second column vector, and the psychometric validity of *g* (Jensen, 1998, pp. 380–383). te Nijenhuis and van der Flier (2013) propose various methods for correcting the results of MCV for these sources of measurement error, which will be implemented in our own analysis.

Aggregation of the three, measurement error corrected vector correlations will yield an aggregated estimate of the population vector correlation, along with 95% CI and a measure of between-study heterogeneity.

Secular trend analysis

The final objective will be to use the aggregate *g* difference between sinistral and dextral populations to derive an estimate of the predicted change in *g* due to the secular increase in sinistrality. McManus et al. (2010) graphed the results of their final meta-analysis (in which all data-sources are analyzed) of the secular trend in the prevalence of sinistrality in their Fig. 8 (McManus et al., 2010, p. 202). Their analysis used two Weibull functions (which are based on continuous probability distributions) weighted based on the square root of the sample sizes to produce best fitting curves through their data. This results in a single best-fitting composite curve characterized by a decrease in sinistrality prevalence between 1830 and 1900 of around 3%, followed by an increase in the prevalence of around 9% between 1900 and 1950, after which the prevalence stabilizes at around 12% of the population.

This change in prevalence can be converted into a change in *g*. To do this the *g* of the dextral population can be fixed at 100, and the *g* of the sinistral population can be fixed at 100-*b* (the *g* difference between dextrals and sinistrals). Therefore, if the *b* value is one IQ point, the value assigned to the sinistral population is 99. Based on this, the percentage of each handedness group can be used as the weighting term in computing a weighted population average *g*, therefore if dextrals are 90% of the population and sinistrals are 10%, the average of 100 and 99, weighted by 90 and 10 respectively gives us the group-level *g* (99.9). As the ratios change with time, the average *g* will change in proportion.

As the values are clearly unimodally distributed (the prevalence of sinistrality decreases between 1830 and 1900, and then increases between 1900 and 1980), the distribution is reanalyzed using a regression discontinuity plot implemented in SPSS v.21.

Results

Estimating the group difference in g

The *g* factor scores were extracted from all three batteries using principal axis factor analysis with oblimin rotation. In all cases, the *g* factor variance accounted for > 50% of the variance. The reliability (estimated using Cronbach's alpha) of the *g* factor was found to be high for both the ASVAB (α = .88) and CAT-ASVAB (α = .783), and for the NCDS ability battery (α = .91).

Table 1 presents the correlations between the *g* factor scores controlled hierarchically for age and sex (and sex only in the case of the NCDS data, as all participants were of the same age at evaluation), along with corrections for reliability and validity, and also the

Table 1
The age and sex corrected correlation between handedness and *g* (*r*) from three samples (NLSY'79, NLSY'97 and NCDS), the reliability and validity corrected correlation (r_{xx}), the reliability and validity corrected unstandardized regression coefficient (b_{xx}), scaled as a difference in IQ points between dextrals and sinistrals respectively, and the sample size (*N*).

Sample	*N*	*R*	r_{xx}	b_{xx}
NLSY'79	8399	.014	.017	.688
NLSY'97	6112	.027*	.034*	1.45
NCDS	8990	.016*	.019*	1.56

* $p < .05$.

Table 2
The aggregate population correlation (ρ_{xx}) corrected for measurement error and unstandardized regression coefficient (b_{xx}) across the three studies, along with combined sample size (*N*), 80% CI of ρ_{XX} and heterogeneity statistic (I^2).

Samples	*K*	*N*	b_{xx}	ρ_{xx}	80% CI	I^2
NLSY'79, NLSY'97 & NCDS	3	23511	1.22	.022*	.018 to .026	.00

* $p < .05$.

measurement error corrected *b* values (i.e. the raw difference between the groups in IQ points). Positive correlations indicate a cognitive advantage to dextrals.

Table 2 presents the results of the aggregation analysis. The value of the I^2 statistic is 0 indicating no heterogeneity between studies. Aggregation studies employing small values of *K* are known to yield biased estimates of heterogeneity however (von Hippel, 2015). Therefore, this estimate may have only limited utility.

Analysis involving MCV

The *b* values and hierarchically age and sex corrected *b* values were computed separately for each subtest in each sample. Vector correlations were computed separately for each sample via Pearson product moment correlation of the column vector of *g* loadings and the column vector of *b* values.

Range restriction among the *g* loadings was estimated relative to a meta-analytically derived reference value sourced from US and Dutch WISC-R and WISC-III standardization samples (.128; te Nijenhuis and van der Flier, 2013). This was achieved by dividing the battery-specific standard deviations by the reference value. In the case of the NLSY'97 range restriction was present, necessitating an upwards correction (*u*) of .859. In the case of the NLSY'79, range restriction was also present, yielding a *u* value of .586. In the case of the NCDS battery, *u* surpassed unity, therefore no correction for range restriction was required. The reliability of the vector of *g* loadings could be estimated using te Nijenhuis and van der Flier's meta-analysis of the *g* vector reliability-sample size relationship. These researchers recommend a value of .97 where $N \geq 3000$, as is the case with all samples used in the present analysis. The reliability of the vector of *b* values cannot be estimated with reference to meta-analytic data, however by correlating the vector of *b* values from both NLSY'79 and NLSY'97 for the overlapping subtests the value of this coefficient can be approximated, yielding a value of .459 – which suggests substantial unreliability in this vector. The imperfect psychometric validity of *g* is estimated at .9, based on Jensen (1998, p. 383). Division of the vector correlations first by *u*, then by the square root of the reliability of the *g* vector, then by the square root of the reliability of the *b* vector and finally by the psychometric validity of *g* yields the measurement error corrected vector correlations. The handedness *b* value associated with the coding speed subtest in NLSY'79 was > 2 standard deviations from the mean across values, suggesting that it is an outlier. Removal of this value yielded a positive vector correlation value among the remaining vector elements ($r = .693$). Correcting this value for the sources of measurement error described above boosts the value to > 1, indicating overcorrection stemming from the presence of second order sampling error among the vector elements, thus it was assigned a value of 1.00 for the purposes of the aggregation step, based on the assumption that sampling error accounts for

Table 3
The *g* loadings and group-difference *b* values (estimates of IQ difference) for each subtest in each battery along with the uncorrected and corrected vector correlations.

NLSY'79			NLSY'97			NCDS		
Subtest	*g* loading	*b*	Subtest	*g* loading	*b*	Subtest	*g* loading	*b*
General Science	.880	.706	*General Science*	.871	.750	*Copying Designs (1)*	.470	1.290
Arithmetic Reasoning	.861	.493	*Arithmetic Reasoning*	.865	1.470	*Draw A Man (1)*	.464	.105
Word Knowledge	.886	.816	*Word Knowledge*	.862	.420	*Southgate Group Reading (1)*	.704	.885
Paragraph Comprehension	.830	.370	*Paragraph Comprehension*	.851	1.305	*Problem Arithmetic (1)*	.611	.630
Numerical Operations	.726	.386	*Numerical Operations*	.65	1.125	*Verbal General Ability (2)*	.880	1.515
Coding Speed	.654	1.715	*Coding Speed*	.601	1.590	*Non-Verbal General Ability (2)*	.816	1.815
Auto-Shop Information	.730	−.417	*Auto Information*	.611	.420	*Reading Comp. (2)*	.840	.915
Math Knowledge	.809	−.066	*Shop Information*	.657	.315	*Math Comp. (2)*	.889	.930
Mechanical Comprehension	.798	.517	*Math Knowledge*	.863	1.005	*Copying Designs (2)*	.383	1.230
Electronic Information	.822	.193	*Mechanical Comprehension*	.821	.945	*Reading Comp. (3)*	.821	.645
			Electronic Information	.815	1.155	*Math Comp. (3)*	.774	.990
			Assembling Objects	.707	1.515			
	Vector correlation			**Vector correlation**			**Vector correlation**	
Uncorrected	−.202* (.693*†)			.033*			.260*	
Corrected	−.574* (1.00*†)			.064*			.433*	

Note: In the case of NCDS subtests the number refers to the survey Sweep in which the data were collected, 1 = age 7, 2 = age 11 and 3 = age 16.
* $p < .05$ for an *N* of 8399 in the case of NLSY'79, 6112 in the case of NLSY'97 and 8990 in the case of NCDS.
† With coding speed removed from NLSY'79.

Table 4
Aggregate vector correlations ($\rho_{xx}(g^{*}b)$) corrected for measurement error along with 80% CI and I^2 heterogeneity value.

Samples	K	N	$\rho_{xx}(g^{*}b)$	80% CI	I^2
NLSY'79, NLSY'97 & NCDS	3	23511	−.023*	−.027 to −.019	1.00*
NLSY'79 (with coding speed removed), NLSY'97 & NCDS	3	23511	.539*	.543 to .535	1.00*

* $p < .05$.

all variance (Hunter and Schmidt, 2004, pp. 399-401). There were no outlying handedness *b* values in NLSY'97 or NCDS. Table 3 presents the *g* loadings by subtest, along with *b* values and both raw and measurement error corrected vector correlations.

The results of the aggregation analysis of the vector correlations are presented in Table 4 using both the NLSY'79 cohort with and without the coding speed subtest. The I^2 values were at unity in both analyses, suggesting extremely high heterogeneity, however, as was mentioned, aggregation studies employing small values of *K* will often produce biased estimates of heterogeneity and is therefore of limited utility (von Hippel, 2015).

Estimating the secular decline in g from the increase in sinistrality

Data on the percentage of sinistrals in Western populations (principally the US and UK) are obtained visually at decadal intervals from the composite of the best-fitting Weibull functions (the black curve) from Fig. 8 in McManus et al. (2010). As the earliest data-point comes from a cohort born approximately in 1830, and the most recent comes from one born approximately in 1980, these decades are used as the beginning and end points, which means that data are collected for 15 decades in total Table 5).

Based on the results of the regression discontinuity plot, the interaction of birth decade with century (19th vs 20th century) was found to be moderate to large in magnitude (semipartial $r = .598$, $p < .05$, beyond the main effect of birth decade) when predicting *g* in a General Linear Model (Type I sum of squares).

Fig. 1 graphs the secular change in *g* over 16 decades due to the changing percentage of sinistrals with regression lines generated using the regression discontinuity plot.

Discussion

Aggregation analysis of three, large and representative datasets indicates a small-magnitude but statistically significant measurement error corrected correlation between *g* and handedness ($\rho_{XX} = .022$), which is associated with a group-difference in *g* between sinistrals and dextrals (b_{xx}) of 1.22 IQ points, favoring the dextrals. The heterogeneity statistic indicates no significant heterogeneity across samples ($I^2 = .00$, *ns*), which suggests that there is no significant between-study variation (*cf.* von Hippel, 2015).

This is not the first study to use these datasets in estimating cognitive ability differences between sinistrals and dextrals. Goodman (2014) utilized these, and other large samples to determine the group difference in terms of cognitive ability, however that researcher computed the differences using a composite of only "math" and "reading comprehension" scores obtained from each battery. The

Table 5
Percent sinistrals, estimated *g* (assuming a mean dextral *g* of 100 and a mean sinistral *g* of 98.7 and fixing the 1980 *g* at 100) and *g* predicted based on the regression discontinuity plot by birth decade and the total and decadal change in *g* between 1830 and 1900, 1900 and 1980 and 1830 and 1980.

Birth decade	*Percent sinistrals*	*Estimated g*	*Predicted g*
1830	6.2	100.07	100.07
1840	5.5	100.079	100.08
1850	4.9	100.086	100.09
1860	4.1	100.096	100.09
1870	3.9	100.098	100.10
1880	3.5	100.103	100.10
1890	3.3	100.106	100.11
1900	3.3	100.106	100.11
1910	3.55	100.103	100.09
1920	4.85	100.087	100.07
1930	7.3	100.057	100.06
1940	10.0	100.024	100.04
1950	12.0	100.00	100.03
1960	12.0	100.00	100.01
1970	12.0	100.00	99.99
1980	12.0	100.00	99.98
Period	$\Delta g_{(total)}$	$\Delta g_{(decade)}$	
1830–1900	.04	.006	
1900–1980	−.13	−.016	
1830–1980	−.09	−.006	

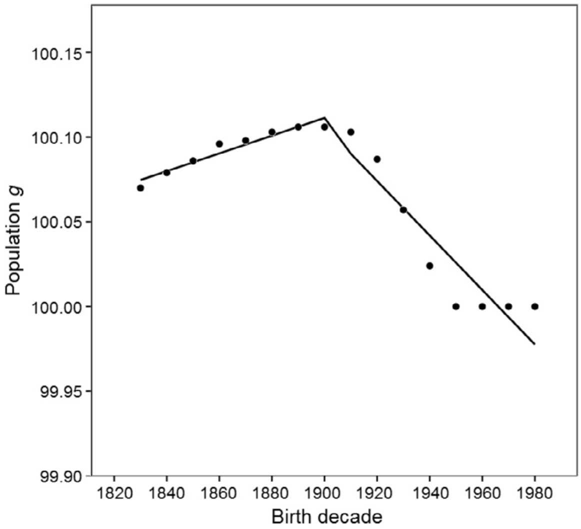

Fig. 1. Regression discontinuity plot fitted to the secular change in *g* estimated from the change in the percentage of sinistrals, 1830 to 1980.

present analysis develops Goodman's analysis via aggregating the handedness-cognitive ability association at the level of the *g* factor variance extracted from each sample using the entire range of ability measures. Nevertheless, we note a similar pattern among our results to that reported by Goodman, specifically with respect to the NLSY'79, which yielded non-significant associations between handedness and cognitive ability in both sets of analyses, despite the direction of the correlation being consistent with theoretical expectations and with results from other samples.

Another way in which the present analysis improves on previous efforts is in the use of MCV in order to determine the degree to which the *g* loading of abilities moderates their association with handedness. The results indicate the presence of statistically significant measurement error corrected vector correlations in all samples, the aggregate of which is a very small magnitude, but statistically significant anti-Jensen effect ($\rho_{xx} = -.023$, $K = 3$, $N = 23511$). Removing the coding speed subtest from the NLSY'79 sample, yielded a large magnitude positive vector correlation ($\rho_{xx} = .539$, $K = 3$, $N = 23511$). The estimate is associated with a high I^2 value (1.00, $p < .05$) which indicates high levels of heterogeneity (*cf.* von Hippel, 2015).

The outlying large association between handedness and coding speed suggests important contributions from the group factor-specific variances in processing speed to the sinistral-dextral group difference. Independently of this however, the overall relationship is a Jensen effect consistent with results found using other markers of developmental stability (e.g. fluctuating asymmetry, Prokosch et al., 2005; Yeo et al., 2016).

Based on secondary analysis of secular trend data on the changing proportion of sinistrals over 16 decades and all else being equal, *g* should have increased between 1830 and 1900 by .006 points per decade. It should then have declined between 1900 to 1980 to a greater degree (.016 points per decade). The overall trend will have been a decrease in *g* of .006 points per decade. It is important to note that this estimate is likely an imperfect indicator of the degree to which *g* can be expected to change based on the underlying decline in developmental stability. To obtain the disattenuated decline in *g* it would be necessary to correct these decadal decline estimates by the degree to which handedness is an imperfectly valid measure of latent developmental stability. No estimates of the validity of handedness as a measure of developmental stability exist however, therefore this correction, whilst sound in theory, cannot be made in practice.

It might be possible to explain the trend in sinistrality in terms of cultural pressures: the Industrial Revolution involves the development of machines made for dextrals, sinistrals were thus at a disadvantage and so pressure is exerted to be right-handed in all respects and more recently this pressure has been relaxed and the true proportion of left-handers in manifesting itself. However, this seems unlikely as these secular trend data complement those suggestive of similar secular trends in other indicators of developmental stability, such as fluctuating asymmetryand other 'somatic modifications' (Woodley of Menie et al., 2017). Also, the earlier data relate to hand-usage other than with regard to writing or operating machinery, such as waving, which would be highly spontaneous and unlikely to be subject to pressure towards right-handedness (McManus and Hartigan, 2007; McManus et al., 2010). The existence of the secular trend in sinistrality also begs the question as to its cause. One possibility is that the overall increase in sinistrality may be caused by fertility patterns favoring sinistrals relative to dextrals. Genetic influences account for about 24% of the variance in handedness (Medland et al., 2009), therefore if sinistrals out-reproduce dextrals this may lead to an increase in the proportion of the former. A key problem with this hypothesis is that the data indicate that dextrals exhibit higher fertility than sinistrals (Gangestad et al. 1996; McManus and Bryden, 1992; McKeever et al., 2000). On this basis it must be concluded that something other than fertility differentials are driving the secular trend. Another possibility, as discussed in the introduction, is that the trend is being driven in part by the accumulation of deleterious mutations owing to relaxed purifying selection (Woodley of Menie et al., 2017). Specifically, mutations affecting genes governing the degree of bodily left-right asymmetry, such as PCSK6 (Brandler et al. 2013) may be causally involved in the secular trend.

Another contributor to decreased developmental stability, and to sinistrality in particular may be increasing pre and perinatal stress stemming from secular trends towards increasingly delayed maternity in Western populations (e.g. Astolfi et al., 1999; Wilkinson et al., 1998). Enhanced pre and perinatal stress may mediate the impacts of various environmental factors on the risk of sinistrality, including exposure to neurotoxic substances (Salvesen et al., 1993) and pathogen exposure (Ramadhani, et al., 2006).

In conclusion, these findings are broadly supportive of declining developmental stability and also the idea that such a decline may potentiate the *g* lost on the basis of factors such as genetic selection. Future research could expand on the nomological net of potential indicators of developmental stability that are undergoing secular declines, deriving predictions of the degree to which *g* might be expected to decline that could be meta-analyzed in a future study.

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