Prevalence and Heritability of Handedness in a Chinese Twin and Singleton Sample

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Abstract

Background: Left-Handedness prevalence has been consistently reported at around 10% with heritability estimates at around 25%. Lower prevalence has been reported in Asia, but it remains unclear whether this is due to biological or cultural factors. Higher left-handedness prevalence has been reported in males and in twins. Most studies are based on samples with European ethnicities and using the preferred hand for writing as the key assessment. Here, we investigated Chinese singletons (N=425) and twins (N = 205 pairs) using both the Edinburgh Handedness Inventory and Pegboard Task, the latter leading to a continuous measure of handedness (PegQ).

Results: We found a higher prevalence of non-right handedness (8%) than what was previously reported in Asian datasets and no evidence of increased left-handedness in twins. We also found some evidence that males have a higher tendency to be left-handed than females. Heritability was similar for both hand preference (21%) and PegQ (22%). However, these two handedness measures present only a moderate correlation (.42) and appear to be underpinned by different genetic factors.

Conclusion: In summary, we report new reference data for an ethnic group usually underrepresented in the literature. Our heritability analysis supports the idea that different measures will capture different components of handedness and, as a consequence, comparisons of datasets assessed with heterogeneous criteria are not easily combined or compared.

Keywords: handedness; Edinburgh Handedness Inventory; pegboard; Chinese children; twins

Background

Handedness, the dominance of one hand over the other, is a commonly observed bias in human behavior and is probably the most studied human asymmetry. Handedness can be determined by measures of *preference* or *performance*. Preference is measured as a binary category indicating the preferred hand for a specific task (i.e. left v right), whereas performance measure assess the abilities of one hand versus the other, leading to continuous measures or handedness indexes.

The most frequently used preference measure is the hand used for writing, which classifies people as left- or right-handed writers. More rarely, individuals with no clear preference are classified as ambidextrous. Hand preference is also assessed on the basis of a range of daily activities usually measured through standard questionnaire that collect self-reported answers or observations, such as the Annett Hand Preference Questionnaire [1], the Edinburgh Handedness Inventory [2], and the Waterloo Handedness Questionnaire [3]. These are represented by J-shaped distributions with most people preferring one hand over the other for most activities and the rest falling in different combinations in the middle. Accordingly, the classification of individuals clusters in categories (e.g. strongly left/right-handed, weakly left/right-handed, and mixed-handed) using cutoff points.

Handedness indexes are derived from well-established tasks including Annett’s peg moving task [1], Peters and Durding’s finger-tapping task [4] and Tapley and Bryden’s dot-filling task [5]. The indexes are derived by comparing how better one hand performs over the other and provide measures of both the degree and direction of handedness. Although they are more informative, laterality indexes generally require one-to-one assessment and therefore are not time/cost effective.

Hand preference for writing is by far the most used measure. A recent meta-analysis estimated that the prevalence of left-hand preference in the general population is 9.2%, with a range between 7.9% - 15.4% based on data from over 2 million of people [6]. The study also confirmed the effect of some factors influencing hand preference including age, sex, and ethnicity reported in previous research. For example, males are more likely to be left-handed than females [7]; Participants of European ancestry have higher prevalence of left-handedness compared to participants of East Asian ancestry [8].

The etiology and determinants of handedness are still unknown, but many studies have provided evidence of genetic influence on handedness. For example, a child with one left-handed and one right-handed parent is 2~3 times more likely to be left handed compared with a child with two right-handed parents, and this ratio increases to 3~4 for a child who has two left-handed parents [9]. Twin studies found that identical twins are more likely to be concordant for hand preference than non-identical or fraternal twins [10]. Medland et al. conducted two large-scale meta-analyses that reviewed a large amount of handedness heritability studies in the literature [11, 12]. Their first study analyzed data from 35 samples of over 21,000 twin pairs from different countries and found that around 25% of the variation in handedness is explained by genetic influences and the rest is explained by environmental factor [11]. Their other study of over 25,000 Australian and Dutch twin families showed again that the genetic influence accounted for around a quarter of variance in hand preference [12].

Less data is available for heritability estimates of handedness indexes or handedness performance. For example, of all the studies analyzed by Medland and colleagues [11], only one used a performance-based measure, i.e. tapping task, and its heritability estimate is nearly zero [13]. In addition, very few studies have looked at the heritability estimates for handedness in populations of non-European ancestry. The prevalence of left-handedness has been consistently reported to be lower in Asia compared to Europe and North America [6, 14, 15]. This difference could be explained by both population-specific genetic or cultural factors. It is clear that stigma against left handedness is an influencing factor which persists in Asia [16-18]. Furthermore, the same societal attitude is reflected in a prevalence of decrease in left-handedness with an increase in age [19]. It is not uncommon to hear how left-handers might have been forced to use the right hand for writing, especially in older generations. Therefore, assessing handedness heritability in younger participants from Asian populations and characterized with measures of both direction and degree might help to better capture the underlying genetic and environmental components.

Left-handedness has been reported to be more prevalent in males and in twins. A large meta-analysis of 144 studies with a total of 1.7 million participants found a sex effect on handedness with a male-to-female odds ratio of 1.27 [7]. The sex difference may be due to the innate biological differences between males and females or culturally transmitted social influences. An increase of left-handedness prevalence has also been reported in twins in a number of studies [10, 12, 20, 21]. However, others have studies failed to find differences between twins and singletons left-handed [22-26]. A complication is that twins and singletons were seldom assessed using the same handedness criteria, recruited in the same manner, or matched for age and sex in these studies.

This study addresses these research questions and gaps in the field by investigating a new sample representative of Hong Kong school-aged children with a set of unique characteristics including: Asian ancestry, a twin and singleton composition, and handedness assessed with different measures, namely the Edinburgh Handedness Inventory (EHI) and the Pegboard task. More specifically, we investigated:

1) the distribution of handedness in Chinese school-aged children;

2) sex effects on handedness preference and performance;
3) differences between twins and singletons;
4) heritability estimates; and
5) the correlation between different handedness measures and whether they share similar genetic and environmental influences.

Materials and Methods

Participants

Participants of this study were selected from the Chinese-English Twin Study of Biliteracy, an ongoing longitudinal twin study which focuses on the genetic and environmental influence on the bilingual development of Chinese children [27]. Twin children from Hong Kong primary schools, with Cantonese as their native language, were recruited for this study. Around four hundred twin pairs have participated since 2015. They were tested on a battery of Chinese language, English language, and cognitive ability tests in the first wave of assessment and were assessed two more times at one-year intervals. Singleton children were also recruited from the same schools as those attended by twins. They were matched with twin participants for age, sex, and grade. The singleton children were assessed once, between the first and the second wave of twin's data collection.

Handedness data were collected from the twin participants during the second wave of assessment. The sample for the current analysis comprised 410 twin children (or 205 twin pairs) and 426 singleton children. The average age of these twins was 8.7 years (SD=1.2; age range 6.7~12.2), and the average age of singletons was 8.3 years (SD=1.2; age range 6.3~12.0). The twin sample consisted of 91 monozygotic pairs (41 male pairs and 50 female pairs) and 114 dizygotic pairs (25 male pairs, 21 female pairs, and 68 opposite-sex pairs). Twin zygosity was determined by genotyping the same-sex twins testing small tandem repeat (STR) markers on chromosomes 13, 18, 21, X and Y by Quantitative Fluorescence-Polymerase Chain Reaction (QF-PCR) [28]. The singleton sample consisted of 221 boys and 205 girls.

Measures

Handedness questionnaire

Handedness preference was assessed using a modified questionnaire based on the Edinburgh Handedness Inventory (Oldfield, 1971). The questionnaire was translated into Chinese and includes 10 items: (1) writing, (2) drawing, (3) throwing, (4) holding scissors, (5) brushing teeth, (6) chopsticks, (7) spoon, (8) knife without fork, (9) broom (upper hand), (10) opening box lid. One item in the original Edinburgh inventory, “striking a match”, was deemed unsuitable for children [29, 30]. It was replaced by a more culturally relevant item “using chopsticks”, which was reported to be learned by Chinese children as early as 5 years old [31]. The full version of the translated questionnaire can be found in Additional file 1.

For each activity, respondents needed to indicate which hand they prefer to use, i.e. left hand, right hand or no preference, and then to what degree they use the preferred hand. The self-reported responses were recorded in two columns labeled *Left* and *Right*. If a preference to use a particular hand is “Always”, 2 points are put in the preferred column. If a preference is “usually”, 1 point is put in the preferred column. If both hands are preferred equally, 1 point is put in both columns. A handedness degree score was computed by the formula (RH-LH)/(RH+LH), where RH is the summed score of the right-hand column, and LH is the summed score of the left-hand column. This EHI score ranges from -1 (all 2 points in the Left column) to +1 (all 2 points in the Right column). EHI reflects both direction and degree of hand preference:

A greater positive score indicates stronger right-handed preference, and a lower negative score indicates stronger left-handed preference.

Handedness direction was determined by a simple transformation of EHI score using a cutoff point. We followed the original criterion set by Oldfield [2] and used the score of zero as the cutoff. By adopting this criterion, we created a binary variable with 1 indicating right-handers and 0 indicating non-right-handers. We didn't separate the latter category further into left-handers and mixed-handers due to small number of participants scoring exactly zero. This new binary variable was named *EHI2*.

Considering the widespread use of writing hand to define handedness in previous research, we selected two singlet items from Edinburgh Handedness Inventory as additional hand preference indicators. Specifically, we recoded the first two questions of the Edinburgh Handedness Inventory related to writing/drawing hand into two binary variables coded as '1' (writing/drawing with the right hand) and '0' (writing/drawing with the left hand or no preference). Discrepancy between preference for writing and drawing might identify pressures of enforcing the use of the right hand for writing.

PegQ

A continuous handedness index (PegQ) was derived from the pegboard task developed by Annett (1970). The task measured the time taken by a participant to move a row of 10 dowel pegs, as fast as possible, across two rows of holes. Five trials were performed with each hand, starting with the preferred hand for writing. The average time of the three best trials out of five was calculated for the right (R) and left (L) hand. PegQ was calculated as $2\times(L-R)/(L+R)$. A positive PegQ scores therefore indicates faster or better right-hand and a negative score indicates better left-hand. Similar to what we did for EHI, a handedness performance direction score named *PegQ2*, was converted from PegQ using the score zero as the cutoff point. PegQ2 was coded '1' if PegQ is positive and '0' otherwise.

Heritability Analysis

Six handedness measures were used in the present analysis: writing hand, drawing hand, EHI, EHI2, PegQ and PegQ2. Heritability of different handedness indicators were estimated using a classical twin design in which phenotype variance was partitioned into that due to additive genetic (A), share environmental (C) and non-shared environmental influence (E). The proportions of variance explained by each component of influence were estimated with structural equation modeling and the proportion of variance explained by the genetic influence (A) gives heritability. Using this technique, we fit an ACE model and compared it with its constrained models, such as AE (dropping shared environmental component) or CE model (dropping genetic influence completely).

Univariate ACE model was first fit on the data, separately for each handedness indicators. We first ran a sequence of models to test equality of model parameters by setting them to be equal across different zygosity, twin order, and sex groups. After establishing the homogeneity of all parameters, we tested the full ACE model and compared its fit with various constrained models.

Next we conducted a bivariate ACE model analysis using the standard Cholesky decomposition approach [32]. The method simultaneously decomposes the variance of two traits into separate variance components which can be represented in a path diagram with six genetic and environmental factors (Figure 1). The figure shows one set of latent variance components

(A1, C1, and E1) is associated with EHI and also with PegQ, whereas another set (A2, C2, and E2) is unique to PegQ only. For each of three sources of influence (A, C, and E), we can estimate three factor loadings which enable us to reconstruct estimates of the contribution of this influence to the variance of EHI, the variance of PegQ and the covariance between them. Our analysis started with the full ACE bivariate model. Then we tested whether the full model could be modified to a more parsimonious models by dropping some of the parameters.

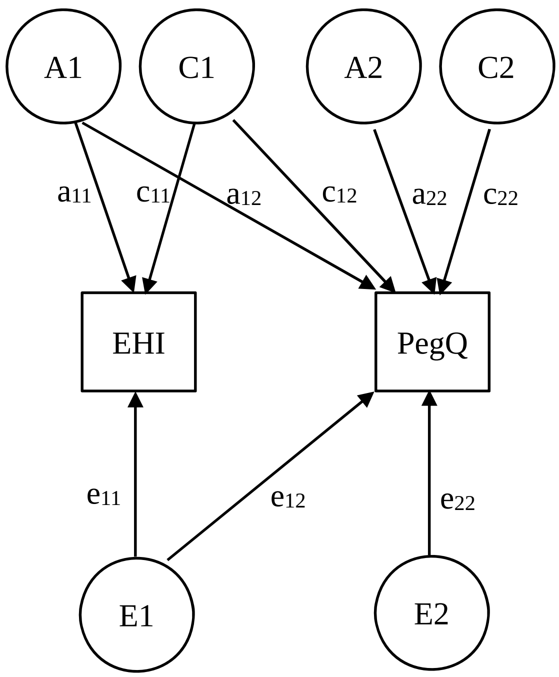

Figure 1 Bivariate Choleskey decomposition of variance and covariance of EHI and PegQ

The univariate and multivariate genetic analyses were performed using the OpenMx software package 2.12.2 [33]. The program to estimate heritability was adapted from the OpenMX scripts distributed on the International Workshop on Statistical Genetic Methods for Human Complex Traits [34]. All codes for the current analysis can be found in Additional Files 3-5.

Results

Sex and twin effects on handedness preference

A total of 384 twin children and 424 singletons responded to the Edinburgh Handedness Inventory. For each task listed in the questionnaire, responses were collapsed into three categories: left-hand preference (‘always left’ & ‘usually left’), right-hand preference (‘always right’ & ‘usually right’), and no preference (Table 1). Proportions of each handedness group were compared between males and females and between twins and singletons with a series of cross-tabulation analyses. A 3x2 chi-square contingency test was conducted in each analysis to test for significant difference.

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The EHI data show that there were slightly more left-handed writers in the twin sample (7.0%) than in the singleton sample (5.9%). If no-preference writers are also taken into account, the proportions of non-right-handed children in the two samples were about equal at 8%. For the ‘drawing hand’, there were also slightly more left-handers (7.3%) in the twin children than in the singletons (6.6%). When taking account of children without a preference, the numbers of non-right-handers increased to 12.2% and 13.2%, respectively, in the two samples. This implies that a small number of children switched or were pressured to use the right hand for writing.

Specifically, we identified 0.9% children (2 twin children and 5 singletons out of the total 808 questionnaire respondents) who wrote with their right hand but drew with their left hand, and there were another 5.0% (17 twins and 23 singletons) who were right-handed writers but reported no hand preference for drawing. Furthermore, we compared the writing task with the eight activities other than writing or drawing and calculated the sum score of each hand without these two items. We identified 2.2% children (4 twins and 14 singletons) who reported writing with the right hand but show an overall preference for the left hand (i.e., their summed score of the left-handed items excluding writing/drawing was greater than the right-handed sum). Based on these data, we estimate that 2~5% children might have been pressured to switch to their right hand when writing.

Comparison between twins and singletons showed significant difference for four tasks (‘throwing’, ‘using spoon’, ‘using knife without fork’, and ‘opening a box’). For example, when asked which hand they use to ‘throw’, 55.7% twins versus 46.9% singleton said they used the right hand. The discrepancy seems to show that twins are more right-lateralized and singletons are more left-lateralized. When comparing males and females, two items (‘throwing’ and ‘holding scissors’) showed differences in the singleton sample only. There are more girls who prefer to use their right hand than boys when they throw (52.9% vs. 41.4%) or when they hold scissors (80.9% vs. 70.0%). However, neither difference was found statistically significant between sexes in the twin sample.

Next we assessed in the twins and singletons the proportion of non-right-handers using writing hand preference, drawing hand preference, and the derived EHI2 and PegQ2 measures (Table 2). Overall our analysis found no significant difference and do not support previous findings suggesting a higher prevalence of left-handedness in twins compared to singletons [35, 36]. In fact, we observed the opposite trend for some measures: 12.2% vs. 13.2% for the preferred hand for drawing, 6.5% vs. 8.5% for EHI2, and 13.2% vs. 15.3% for PegQ2. Instead, consistent with previous literature, we found that non-right-handers were more prevalent in males than females for both writing hand preference and EHI2, in both twins and singletons. The

PegQ2 measure also detected a higher proportion of left-handed males compared to females but in the singleton sample only.

Table 2 Percent of non-right-handers (NRH) and right handers (RH) by sample and sex for four handedness direction indicators

Handedness	Twins			Singletons			Total		
Direction	Male N (%)	Female N (%)	$\chi^2_{(df=1)}$	Male N (%)	Female N (%)	$\chi^2_{(df=1)}$	Twins N (%)	Singletons N (%)	$\chi^2_{(df=1)}$
Writing hand									
NRH	17	14	0.51	19	14	0.46	31	33	
%	(9.1)	(7.1)		(8.6)	(6.9)		(8.1)	(7.8)	
RH	170	183		201	190		353	391	0.02
%	(90.9)	(92.9)		(91.4)	(93.1)		(91.9)	(92.2)	
Drawing hand									
NRH	26	21	0.94	27	29	0.35	47	56	0.17
%	(13.9)	(10.7)		(12.3)	(14.2)		(12.2)	(13.2)	
RH	161	176		193	175		337	368	
%	(86.1)	(89.3)		(87.7)	(85.8)		(87.8)	(86.8)	
EHI2									
NRH	13	12	0.12	20	16	0.21	25	36	1.13
%	(7.0)	(6.1)		(9.1)	(7.8)		(6.5)	(8.5)	
RH	174	185		200	188		359	388	
%	(93.0)	(93.9)		(90.9)	(92.2)		(93.5)	(91.5)	
PegQ2									
NRH	23	29	0.38	40	25	2.87	52	65	0.71
%	(12.1)	(14.2)		(18.1)	(12.2)		(13.2)	(15.3)	
RH	167	175		181	180		342	361	
%	(87.9)	(85.8)		(81.9)	(87.8)		(86.8)	(84.7)	

1) EHI2 and PegQ2 are the binary classification of EHI and PegQ scores respectively, using zero as the cutoff point; 2) 26 twin children and 2 singletons did not participate the questionnaire study but did the pegboard task; 16 twin children did not do the pegboard task but responded to the questionnaire.

We then compared quantitative scores of handedness, measured as EHI and PegQ, between twins and singletons and between males and females. The frequency distribution graph of the two scores can be found in Additional file 2. The EHI mean was .641 (SD=.415) in the twins and .577 (SD=.393) in the singletons, respectively (Table 3). The mean PegQ score was .094 (SD=.101) in the twins and .097 (SD=.100) in the singletons. A sample by sex (2x2) ANOVA shows that EHI was significantly higher in twins than in singletons ($F_{1,804}$=4.84, p=.03), suggesting twins have a stronger right-hand preference than singletons. Furthermore, EHI was marginally higher in females than in males ($F_{1,804}$=3.73, p=.07), indicating that males have a tendency towards left-hand preference. Although twins had a marginally lower PegQ score than singletons indicating stronger left performance, the mean difference was negligible ($F_{1,816}$=0.11, p=.74). PegQ scores were consistently lower in males in both twins and singletons. This pattern is consistent with the observation that males had a lower EHI score; however, the difference was small and non-significant ($F_{1,816}$=0.38, p=.54).

Table 3 Mean EHI and PegQ score by sample and sex

Handedness	Twins		Singletons		Total	
Score	Male	Female	Male	Female	Twins	Singletons
EHI						
N	187	197	220	204	384	424
Mean	.618	.662	.548	.607	.641	.577
SD	.422	.410	.427	.351	.416	.393
PegQ						
N	190	204	221	205	394	426
Mean	.093	.096	.094	.099	.094	.097
SD	.097	.105	.106	.093	.101	.100

Correlation between different handedness measures

Correlations across laterality measures and their association with age and sex show similar patterns in the twin and in the singleton sample (Table 3). PegQ was moderately correlated (about .40) with both preferred hand for writing and EHI in both samples. A similar correlation was found between their binary classification scores, EHI2 and PegQ2. Neither EHI nor PegQ was correlated with age and sex.

Table 4 Correlations between age, sex and different measures of handedness in the twin sample (lower triangle) and in the singleton sample (upper triangle)

	Age	Sex	Writing hand	Drawing hand	EHI	EHI2	PegQ	PegQ2
Age		.05	.02	.04	.07	.08	-.06	.02
Sex	.01		.03	-.03	.08	.02	.03	.08
Writing hand #	.00	.04		.62**	.69**	.73**	.40**	.34**
Drawing hand #	-.03	.05	.71**		.67**	.66**	.29**	.24**
EHI	-.02	.05	.80**	.72**		.81**	.42**	.35**
EHI2 #	-.07	.02	.85**	.71**	.84**		.44**	.39**
PegQ	.08	.02	.44**	.37**	.44**	.44**		.70**
PegQ2 #	.08	-.03	.46**	.34**	.43**	.44**	.67**	

Measures marked with # are binary handedness variables with 0='non-right-handed' and 1='right-handed'; Sex is coded as 0='male', 1='female''; * $p < .05$, ** $p < .01$.

Univariate heritability analysis

We conducted a series of univariate genetic analyses to estimate sources of variation in handedness that is due to genetic and environmental influence (Table 5). We compared the full ACE model with its constrained sub-models AE, CE and E only model and tested their differences in fit statistics.

Table 5 Univariate ACE model fitting results for different handedness measures and estimates of variance components of A, C, E

	Proportion of variance			*-2LL* fit to		*ΔLL* (vs. ACE Model)		
Measure	*A*	*C*	*E*	ACE Model	*df*	AE	CE	E
Writing hand #	.27	.00	.73	214	379	0.00	0.67	0.94
Drawing hand #	.24	.00	.76	282	379	0.00	0.84	1.18
EHI	.21	.00	.79	3946	380	0.00	5.39*	5.39
EHI2#	.38	.00	.62	179	379	0.00	0.89	1.78
PegQ	.22	.00	.78	2935	390	0.00	2.23	4.75
PegQ2#	.28	.00	.72	303	389	0.00	0.69	1.38

Measures marked with # are binary handedness variables. $*p < .05$

Heritability or genetic contribution (proportion of A) to various handedness measures was generally low. The highest heritability estimate was found for EHI2 (.38), which was the binary classification of handedness based on overall preference score EHI. However, the estimate was not significant, meaning we cannot exclude an environmental explanation with CE model or E only model. For all other handedness indicators, heritability estimates were consistently in the range of .20 to .30. The heritability for EHI in particular was .21 and a model without genetic component (CE) fits significantly worse than the full ACE model, indicating that the genetic contribution to hand preference is weak but significant.

Bivariate heritability analysis

EHI and PegQ had a correlation of about .40 (Table 4). Through a bivariate genetic analysis using the Cholesky decomposition method, we asked whether this correlation might result from shared genetic influences. The bivariate analysis was performed for only EHI and PegQ (Table 6), because they are continuously distributed, giving us more power to detect additive genetic effect than the categorical measures in our study.

Table 6 Bivariate Cholesky model fitting results for EHI and PegQ and comparisons of nested models

	ACE and nested models	*-2LL*	*df*	*AIC*	*ΔLL*	*Δdf*	*p*
1	Model ACE	6796.36	767	5262.36			
2	Model AE, drop C	6801.79	770	5261.79	5.43	3	.14
2a	**Model AE1, drop a_{12}** (a_{12}=0)	**6802.73**	**771**	**5260.73**	**6.37**	**4**	**.17**
2b	Model AE2, drop a_{22} (a_{22}=0)	6806.98	771	5264.98	10.62	4	.03
3	Model CE, drop A	6806.58	770	5266.58	10.22	3	.02
4	Model E, drop A & C	6813.13	773	5267.13	16.78	6	.01

The best fitted model is highlighted with the bold font.

The full ACE model fit result was tested first (Model 1). Next, we tested whether shared environmental effect, or the two C factors, could be completely dropped (Model 2 or AE). Dropping C did not result in a significant loss in likelihood function statistics (-2LL); therefore, Model 2 was accepted as more parsimonious than the full ACE model. This is consistent with what we have observed in the univariate analyses which found little shared environmental influences on either EHI or PegQ. Furthermore, we tested two reduced models of AE. In Model

2a, we dropped the correlation between the two genetic factors by constraining the parameter a_{12} to be zero. This did not lead to a significant change in fit statistics, indicating the genetic correlation may be dropped and the two genetic factors A1 and A2 are independent. In Model 2b, we tested an alternative model in which a_{12} was kept free but a_{22} was fixed to zero. This is equivalent to dropping A2 from the model, meaning EHI and PegQ share the same genetic influence. However, dropping A2 worsened the fit significantly and thus Model 2b was rejected, implying that sources of genetic influences of EHI and PegQ are not identical. Lastly, we tested two environmental models, the CE model (dropping A completely) and the E only model (dropping both A and C). Fitting both models resulted in a significant reduction in model fit statistics, indicating that a pure environmental explanation of handedness cannot not be accepted.

The above analyses show that a constrained AE model without genetic correlation (Model 2a) explains the variance and covariance of the two handedness measures as well as the full ACE model, but with much fewer parameters. Different models can also be compared using the Akaike information criteria (AIC), a popular model fit index. The model with the lowest value of AIC reflects the best balance of goodness of fit and parsimony. Therefore, Model 2a was accepted as the best bivariate model. For ease of result interpretation, we converted the Cholesky model to an equivalent correlated factor model in which the association between latent factors are modelled explicitly as factor correlations, as recommended by Loehlin [37]. Figure 2 shows model AE (Model 2) and its constrained model (Model 2a) in this representation and all the standardized parameter estimates. The figure shows that variation in EHI and PegQ are influenced by two different additive genetic factors (A1 and A2) and two different environmental factors (E1 and E2). The association between A1 and A2 was non-significant, indicating no or little overlap between genetic influences of EHI and PegQ. The observed association between

EHI and PegQ arose entirely from the correlation of the two environmental factors based on the best fitted Model 2a.

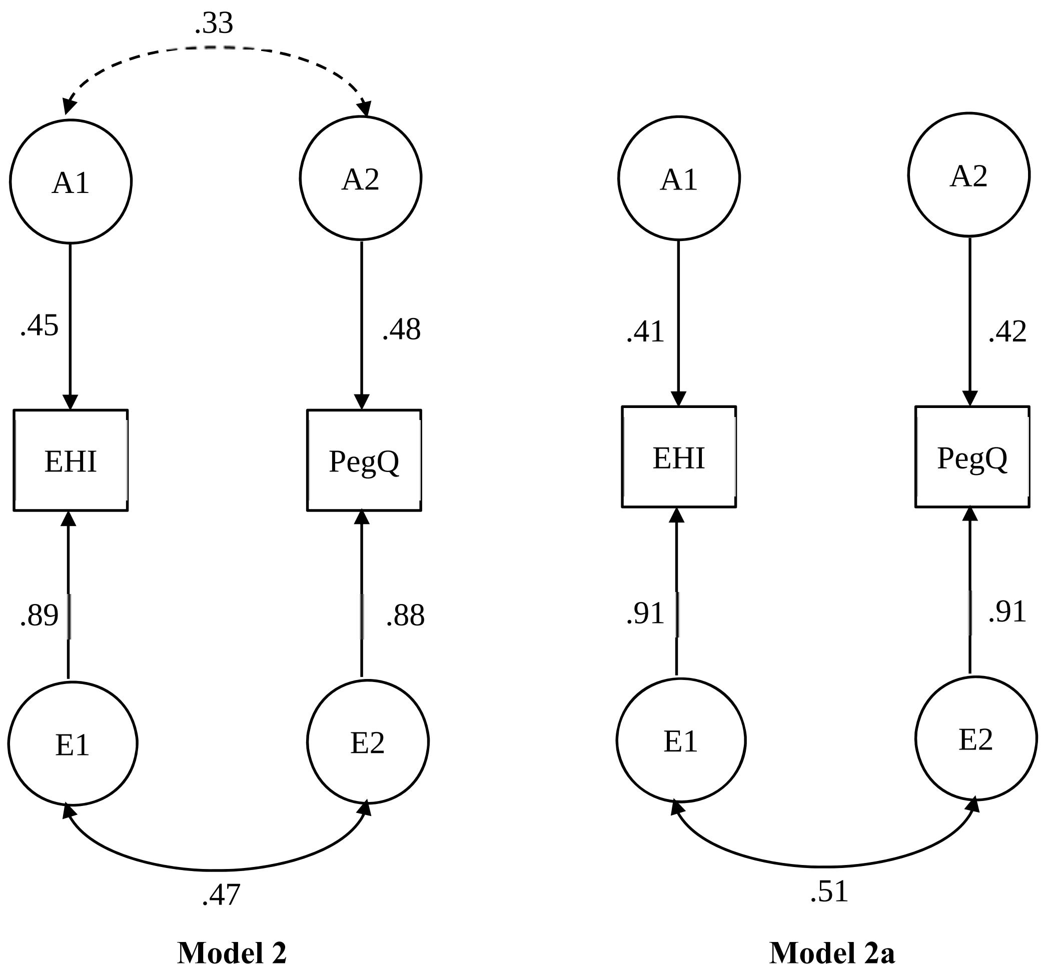

Figure 2 Standardized parameter estimates for the bivariate AE model (Model 2) and its reduced best-fitted model (Model 2a). Dashed line indicates non-significant correlation.

Discussion

In this study we investigated handedness data in over 800 Chinese children using different binary and continuous measures. Our results show that, using writing hand to define handedness, around

8% of school-aged children are left- or non-right-handers. This proportion is slightly lower than the generally reported figure of 10% left-handedness prevalence, but much higher than what was previously shown for in Chinese. A 1980s survey found that less than 1% Chinese students were left-handed writers [18]. However, that data refers to the mainland Chinese population and was collected more than 30 years ago, whereas our study was conducted in Hong Kong, a city culturally influenced by the West. Large-scale population studies in North America and Britain have shown that the prevalence of left-handers varies by birth year and age cohort, and frequency of left-handers is much higher in the younger generations [19, 38]. In Hong Kong, left-handers used to face strong pressure to conform with the majority forced to switch their writing hand at school [39], but our data suggest that recently the pressure in enforcing the use of the right hand for writing has reduced. Although we did not have direct information on possible hand switching experience of our participants, from the difference between writing hand and drawing hand and the difference between writing and other handedness activities, we estimated that the proportion of children in our sample who experienced forced handedness switch is around 2~5%. Including these possible switched-handers, we can state that the incidence rate of left-handedness in the Chinese children is no different from the worldwide average.

The proportion of left-handers derived from the overall handedness preference EHI2 was similar as the proportion of left-handed writers, also around 8% (7% in twins and 9% in singletons). Our result can be compared with a recent study conducted in mainland China, which collected EHI data in a sample of over 1,800 college students [40]. Employing zero as the cutoff score to classify handedness, the study found that less than 4% participants could be described as left-handers, significantly lower than our sample. As pointed out by Xie [41], the pressure against left-hand use still persists in the mainland and there remains discriminatory education policy and practices against left-hander in schools. Considering large geographical and environmental variation, more data are needed to determine the prevalence of left-handedness in the general Chinese population and to track the possible change of attitude and adaptation to handedness diversity over time. Our data suggest that the increase of left-handedness prevalence in Hong Kong in recent time is likely to reflect effects of Westernization. Therefore, it is reasonable to predict that the lower proportion of left-handedness in East-Asian populations is more likely to result from cultural rather than genetic factors.

We also calculated prevalence of left-handedness separately in twins and singletons. we found no evidence that left-handedness is more common in twins as suggested in some previous studies [10, 21]. We did observe a slightly higher frequency of left-handed writer in twins than singletons (7% vs. 6%), but the difference was not significant and nearly non-existent if mixed-handers were taken into account. On the contrary, when we defined left-handedness by the overall handedness preference (EHI<=0), we found that left-handers were more frequent in singletons (9%) than twins (7%). The difference was particularly pronounced when we compared the quantitative score EHI in a multivariate analysis controlling for the age and sex effect, which showed that singletons, rather than twins, have a stronger degree of left-handedness. More left-handers in singletons were also observed when handedness was defined by pegboard performance (PegQ<0). There were 15% singleton children who were better with their left hand compared to 13% in twins, though the difference did not reach statistical significance. Nevertheless, our study contradicted the previous finding that left-handers are more common in twins compared to singletons. The reason for the inconsistent findings might be due to using the overall preference index (EHI) rather than a single indicator of writing hand to define handedness. Our item cross-tabulation analysis shows that a handedness difference between twins and singletons mainly arose from tasks such as throwing, cutlery use, and opening a box etc. It is unclear why there were distinct rates of mixed- and left-handers between them. More research is needed to understand this behavior discrepancy.

Our data support the widely reported finding that there is a higher incidence of left-handedness among males than females [7]. There were 9% of boys in our sample who are non-right-handed writers as compared to only 7% of girls. Male children also showed stronger degree of left-handed preference as reflected by their lower average EHI score. The individual preference item analysis showed that the sex difference was particularly pronounced in the singleton sample. However, our results could not find any significant discrepancy between boys and girls on their pegboard performance scores, continuous or categorical. This is different from a recent study in UK which found females tend to be more right lateralized and males are more left lateralized for PegQ [42]. One possible reason is our sample is too small for the detection of these effects for the performance measure.

Our heritability estimates for various handedness measures are consistent with previous studies. We found that heritability for writing hand preference is .27 (Table 5). It has been well established in previous meta-analyses that around a quarter of handedness variation is explained by additive genetic effect and the remaining is purely non-shared environmental influences [11, 12]. However, the phenotypes used in those studies were predominantly preference measures, especially writing hand, and the samples collected were mostly from North America or Europe. Our heritability estimates for different categorical measures converted from EHI and PegQ ranged from .24 to .38 with the highest figure observed for EHI direction or EHI2. Due to relatively small sample sizes, we could not rule out alternative or environmental explanations of data for these categorical measures.

Our heritability estimates for the two quantitative scores of preference (EHI) and performance (PegQ) were .21 and .22, respectively. These low estimates do not support the idea that quantitative traits might have a higher heritability than categorical data. In particular, Lien et al. reported a high heritability (.52) for the hand preference index in a sample of 640 Chinese college students and their 1300 first-degree relatives [43]. However, we could not find any evidence to support such a high heritability.

The PegQ quantitative measure identified 14~15% children who performed faster with their left hand on the pegboard. Around 2/3 of them also had a left-hand preference by EHI direction. This is consistent with the overall correlation of .40~.50, indicating that the two measures do not map exactly on to each other. These results are consistent with the aforementioned recent study conducted on UK children showing poor correlation across different handedness measures [42]. Our bivariate genetic modelling analysis further revealed that a model with one latent genetic factor did not fit the data. The overlap between genetic influence on handedness preference and performance is very low. Based on our findings, an important implication for future research, especially in molecular genetic studies, is that preference and performance represent two different handedness definitions, and it is important not to use them as interchangeable measures.

There are two major limitations of our study. First, we collected a sample of only about 200 twin pairs; this is a relatively small sample. Schmitz, Cherny and Fulker [44] found that with this sample size, the power to detect genetic correlation of .50 between phenotypes with a heritability of .20~.30 is only around .50 or less. Therefore, although our model fitting results show that the independent genetic factor model (Model 2a) fits the data best, we could not rule out the possible moderate association between their genetic origin due to small sample and low power. Second, our study used only one measure, the pegboard task, to assess handedness performance. However, hand performance itself may not be a one-dimensional trait, but rather a multi-dimensional one that includes different aspects such as dexterity, skill, and strength. Corey et al. found that using a single hand performance did not always correctly classify an individual who has a left-or right-handed preference, but a combination of different measures did [45].

Conclusions

In summary, we report a novel set of data from underrepresented population which allowed us to address questions in the field of laterality research. Our results reinforce the idea that different handedness measures tap into different laterality dimension and provide a reference dataset for studies in Asian populations.

Abbreviations

EHI: Edinburgh Handedness Inventory handedness score

PegQ: Pegboard laterality quotient

LH: Left-handed

RH: Right-handed

NRH: Non-right-handed

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Authors' contributions

MZ drafted the manuscript and performed all the analyses. SP contributed to the ideas for analysis, result interpretation, and editing of the manuscript. CM, CH, and SP conceived and designed the study. KC participated in the twin saliva testing and zygosity diagnosis. JC participated in data collection and contributed to the writing of the method section. All authors read and approved the final manuscript.

Additional files

Additional file 1. The Chinese translated Edinburgh Handedness Inventory

Additional file 2. Distribution of EHI and PegQ in the twin and in the singleton sample

Additional file 3. OpenMx script for the univariate heritability analyses – continuous measures

Additional file 4. OpenMx script for the univariate heritability analyses – categorical measures

Additional file 5. OpenMx script for the bivariate heritability analyses

All files have been uploaded to the Open Science Framework repository (https://osf.io/pcg8m/)

Table 1 EHI data split by sample and sex

Item		Preference (LH=left-hand; RH=right-hand)	Twins		$\chi^2_{(df=2)}$	Singletons		$\chi^2_{(df=2)}$	Total		$\chi^2_{(df=2)}$
			Male % N=187	Female % N=197		Male % N=220	Female % N=204		Twins % N=384	Singletons % N=424	
1.	Writing	LH	7.0	7.1	4.26	7.3	4.4	2.17	7.0	5.9	1.37
		RH	90.9	92.9		91.4	93.1		91.9	93.0	
2.	Drawing	LH	8.0	6.6	1.02	7.3	5.9	2.14	7.3	6.6	1.11
		RH	86.1	89.3		87.7	85.8		87.8	86.8	
3.	Throwing	LH	8.6	10.2	0.32	13.6	6.4	8.99*	9.4	10.1	6.49*
		RH	56.7	54.8		41.4	52.9		55.7	46.9	
4.	Holding Scissors	LH	8.6	6.1	2.86	10.5	9.3	8.57*	7.3	9.9	4.66
		RH	78.1	84.8		70.0	80.9		81.5	75.2	
5.	Brushing Teeth	LH	8.6	6.1	0.89	11.8	5.9	5.75	7.3	9.0	0.81
		RH	67.9	69.0		62.3	71.1		68.5	66.5	
6.	Chopsticks	LH	5.9	7.1	4.19	9.1	6.9	0.73	6.5	8.0	2.01
		RH	89.8	91.9		86.8	89.2		90.9	88.0	
7.	Spoon	LH	8.4	9.0	1.38	9.1	5.9	3.13	8.7	7.5	7.61*
		RH	68.5	72.9		65.0	61.8		70.8	63.4	
8.	Knife without fork	LH	9.6	9.6	3.02	11.9	15.8	4.53	9.6	13.8	11.57**
		RH	76.8	82.4		67.6	70.8		79.7	69.1	
9.	Broom (Upper hand)	LH	16.9	13.9	2.44	18.2	14.7	1.79	15.3	16.5	0.57
		RH	55.6	63.6		54.1	60.3		59.7	57.1	
10.	Opening a Box (Lid)	LR	6.2	10.7	3.38	9.1	10.3	1.61	8.5	9.7	9.10*
		RH	50.0	52.4		38.2	43.1		51.2	40.6	

1) Q6 “chopsticks” is a modified item to replace “striking a match’ in the original Edinburgh Handedness Inventory.

2) For each task the responses were collapsed into three categories: ‘LH’, ‘RH’, and ‘No preference’. Percent of ‘No preference’ respondents is not shown for purpose of simplicity but can be easily calculated by subtracting % of LH and RH from 100%.

3) Group difference for each item was compared by the χ^2 test (3x2) and the significance was marked by * $p < .05$ and ** $p < .01$.