Published in final edited form as:

Learn Individ Differ. 2010 October 1; 20(5): 549–553. doi:10.1016/j.lindif.2010.06.005.

The nature (and nurture) of children's perceptions of family chaos

Ken B. Hanscombe^{1,*}, Claire M. A. Haworth¹, Oliver S.P. Davis¹, Sara R. Jaffee¹, and Robert Plomin¹

¹Social, Genetic & Developmental Psychiatry Centre, Institute of Psychiatry, King's College London

Abstract

Chaos in the home is a key environment in cognitive and behavioral development. However, we show that children's experience of home chaos is partly genetically mediated. We assessed children's perceptions of household chaos at ages 9 and 12 in 2337 pairs of twins. Using child-specific reports allowed us to use structural equation modeling to explore the genetic and environmental etiology of children's perceptions of chaos. We found that these perceptions are significantly heritable (22%), with the remainder explained by environmental influences. Finding that genes influence children's experience of chaotic environments has far-reaching implications for how we conceptualize the family home and its impact on cognitive and behavioral development.

Keywords

gene-environment correlation; household chaos; home environment

The nature (and nurture) of children's perceptions of family chaos

Family life revolves around regular events like mealtimes and bedtimes, is set against varying levels of latent noise (e.g. radio, television, telephone), and is interspersed with the coming and going of various family members and visitors. It is perhaps not surprising then that chaos in the home - that is the levels of environmental noise, crowding and disorganization - predict children's cognitive and behavioural outcomes. Greater household chaos is associated with both lower cognitive abilities (Asbury, Wachs, & Plomin, 2005; Hart, Petrill, Deckard, & Thompson, 2007; Petrill, Pike, Price, & Plomin, 2004) and greater conduct problems (Coldwell, Pike, & Dunn, 2006; Deater-Deckard et al., 2009; Dumas et al., 2005).

Both parents and their children create and shape the home environment, but it is unclear whether a child's experience of chaos in the home is under the influence of genetic factors – either their own genes, or their parents' genes. In other words, do heritable behaviours (of

© 2010 Elsevier Inc. All rights reserved.

*Corresponding author: Ken B. Hanscombe, Social, Genetic and Developmental Psychiatry Centre, Institute of Psychiatry, King's College London, De Crespigny Park, London SE5 8AF, Ken.Hanscombe@kcl.ac.uk Tel: +44 (0) 20 7848 0074, Fax: +44 (0) 20 7848 0895.

Publisher's Disclaimer: This is a PDF file of an unedited manuscript that has been accepted for publication. As a service to our customers we are providing this early version of the manuscript. The manuscript will undergo copyediting, typesetting, and review of the resulting proof before it is published in its final citable form. Please note that during the production process errors may be discovered which could affect the content, and all legal disclaimers that apply to the journal pertain.

either the parent or child) affect the child's perception of household chaos? If genetic factors do influence children's experience of family chaos, established associations between parent-reported chaos and childhood outcomes will need to be re-addressed from the child's perspective. To the extent that genes influence the association, simply reducing the level of chaos may have little long-term effect on child development. This study investigates the genetic and environmental origins of the chaotic home as experienced by the child.

Parent's perceptions of chaos in the home

Household chaos is typically measured by parent reports on the Confusion, Hubbub and Order Scale (CHAOS; Matheny, Wachs, Ludwig, & Phillips, 1995). CHAOS assessed by parent-report is a family-level risk factor for child development, and is necessarily the same for all children in a family. Several studies have examined the extent and pattern of association between parent-reported chaos and other aspects of the family home, including parental warmth and negativity, parent education and IQ, socio-economic status (SES), home literacy environment, and housing quality (Dumas et al., 2005; Evans, 2006; Johnson, Martin, Brooks-Gunn, & Petrill, 2008). Importantly, even when the associations with known psychosocial and environmental risk factors are controlled for, chaos predicts independent variation in cognitive ability and conduct problems establishing both the validity and utility of parent-rated chaos. Recently, Deater-Deckard and colleagues (2009) have found parent-rated chaos to be a valid and independent predictor of both concurrent childhood cognition, and concurrent and longitudinal behavioural outcomes.

Children's perceptions of chaos in the home

Previously, chaos in the home has been treated as a family-wide variable because it has been measured by parent-report. This means that the children in the same family have identical measurements of chaos. However, children growing up in the same family may experience the environment quite differently (Daniels, Dunn, Furstenberg, & Plomin, 1985). Genetically influenced individual differences in behaviour could lead to differential environmental exposure, with exposure experienced more similarly between more closely related individuals: a heritable 'environment'. The home environment – essentially created by and largely under the control of the people living in the home – is likely to be particularly susceptible to genetically influenced behaviours of parents and their children. While parent-reported chaos is associated with cognitive and behavioural outcomes in childhood, analyses that incorporate parent-rated chaos into a genetically informative design as an obligatory-shared environment are limited in the conclusions that they can draw about the nature of the effect of chaos on particular childhood outcomes (Purcell & Koenen, 2005).

It is possible, however, to treat even a measure of the environment as a dependent variable in genetic designs. When individual-specific measures of the environment are treated as a trait, submitting them to a genetically informative design such as the twin method, it becomes apparent that 'environments' themselves are under genetic influence – this has been called *the nature of nurture* (Plomin & Bergeman, 1991). A review of the quantitative genetic literature incorporating both twin and adoption studies concluded that genetic effects on measures of the environment are moderate and pervasive (Kendler & Baker, 2007). Across all the studies, employing a variety of measures assessed by a range of methods, the weighted average heritability was 27%.

A genetic influence on experience of household chaos, a genotype-environment (GE) correlation (Plomin, DeFries, & Loehlin, 1977), would suggest that an individual is not independent of their experience of the home environment (Scarr & McCartney, 1983). Our aim was to extend the research on household chaos into middle childhood. By taking advantage of the fact that at this age it was possible to acquire child self-reports, which was

not possible in earlier studies of younger children (Petrill et al., 2004), we hoped to gain insight into the genetic and environmental factors that influence children's perceptions of chaos. Consistent with the ubiquitous finding of genetic effects on environmental exposures (Jaffee & Price, 2007; Kendler & Baker, 2007), we expected to find modest genetic influence on children's exposure to chaos in the home.

Method

Sample

The sampling frame was the Twins Early Development Study, TEDS (Oliver & Plomin, 2007; Trouton, Spinath, & Plomin, 2002). Data on CHAOS at 9 and 12 years were available for a total of 4,956 individuals; 2,337 complete twin pairs had data at both ages (see Table 2 for summary by zygosity). TEDS is an ongoing population-based, longitudinal study of a large sample of twins born in England and Wales in 1994, 1995, and 1996. The present study describes the results of analyses conducted on the twins' perceptions of chaos in the home at both 9 and 12 years. Mean age at completion of the test battery for the age 9 sample was 9.01 years ($SD = 0.29$), and for the age 12 sample was 11.28 years ($SD = 0.70$). A validated parent-rated instrument, with 95% accuracy when compared to zygosity established from DNA markers, was used to assign zygosity (Price et al., 2000).

At both age 9 and 12 years, the TEDS sample is representative of the United Kingdom (UK) general population. UK census data for families with children indicate that 93% of children are white and 32% of mothers have at least one A-level (non-compulsory exam taken at age 18), while 49% of mothers and 89% of fathers are employed. For the entire TEDS sample of more than 10,000 twin pairs who completed an initial booklet when the children were two years old, the comparable percentages are 92%, 35%, 43% and 92% respectively. For the TEDS sample that participated at 9 years, the respective percentages are 94%, 41%, 46% and 93%; and at 12 years, the comparable percentages are 93%, 41%, 47% and 93%.

Measure

CHAOS: Confusion, Hubbub and Order Scale—At 9 and 12 years the children's perceptions of chaos in the family home were assessed by means of a short version of CHAOS (Matheny et al., 1995). The inventory, consisting of six items measured on a three-point scale, was completed as a 'pencil and paper' task, as part of a larger battery of tests in a booklet posted to each of the twins. The inventory assesses the level of routine, noise, and general environmental confusion with the six items: 'I have a regular bedtime routine' (scoring reversed), 'You can't hear yourself think in our home', 'It's a real zoo in our home', 'We are usually able to stay on top of things' (scoring reversed), 'There is usually a television turned on somewhere in our home', and 'The atmosphere in our house is calm' (scoring reversed). The children indicate the extent to which they agree: "Not True", "Quite True", or "Very True". At both age 9 (Cronbach's $\alpha = .58$) and 12 (Cronbach's $\alpha = .57$), total scores were calculated by summing the individual items coded so that larger scores indicated greater chaos. Parent-reported CHAOS when the children were age 9 and 12 correlates .53 and .55 respectively, with the corresponding 9 and 12-year child reports.

As the purpose of the present study was to establish the origins of middle childhood chaos, we created a composite (the first principal component) of child-reported chaos measured at ages 9 and 12. The increased reliability gained as a result of removing uncorrelated error of measurement is reflected in the twin correlations summarised in Table 2 (e.g., monozygotic twin correlations are 0.65 at 9 years, 0.64 at 12 years, and 0.75 for the composite measure). CHAOS at age 9 and 12, and the composite are normally distributed.

Analyses

The Twin Method—The quantitative genetic model attributes the similarity of twins reared together to additive genetic (A) and shared environmental (C) factors (Evans, Gillespie, & Martin, 2002; Plomin, DeFries, McClearn, & McGuffin, 2008). Nonshared environmental (E) factors and measurement error contribute to twin differences. Comparison of the phenotypic correlations between identical (MZ) twins who are correlated 1.0 genetically, and the phenotypic correlations of fraternal (DZ) twins who are correlated 0.5 (i.e. share on average 50% of their segregating alleles, like any other sibling pair), provides a method for estimating relative contributions of genes and the environment to individual differences on a trait. Heritability is the statistic that quantifies the amount of phenotypic variation on a trait attributable to genetic variation (Rijsdijk & Sham, 2002). To the extent that additive genetic (A) factors are important for individual variation on a trait, we expect a greater phenotypic correlation between MZ twins compared to DZ twins. Considering the degree of genetic relatedness, a DZ twin correlation greater than half the MZ correlation suggests shared environmental (C) influence. The shared environment represents those elements of the environment that have the effect of making siblings growing up in the same family more alike. An MZ twin correlation less than 1 indicates nonshared environment (E): environmental factors that do not contribute to sibling similarity.

Univariate genetic analyses

Standard structural equation model-fitting routines implemented in Mx (Neale, Boker, Xie, & Maes, 2002) were used to fit covariance models to the raw data, with latent genetic and environmental parameters estimated by maximum likelihood. Modelling the covariance structure between both observed and latent factors provides a more comprehensive use of the raw data to calculate variance parameter estimates. The difference in model fit between the full ACE model, and simpler nested models with some parameters dropped, indicates which model is the most parsimonious account of the data. The fit of nested models is judged from the difference in fit statistic (which distributes as chi-square (χ^2)), and difference in degrees of freedom associated with each model – a significant p -value indicates a worse fit relative to the full model. In addition we report the Akaike information criterion (AIC; $AIC = \chi^2 - 2df$; Akaike, 1987), which provides a measure of model fit relative to parsimony, with lower AIC values indicating a better fit.

Results

Means, standard deviations and analyses of variance results by sex and zygosity for CHAOS at 9 years, 12 years, and the composite of child-reported chaos at the two ages, are presented in Table 1. The combined effect of age and sex on the means was negligible ($R^2 = 0.00 - 0.01$). Same-sex twins are perfectly correlated for age and sex, an association that could be misinterpreted as shared environment, so, as is standard practice in the analysis of twin data, all subsequent analyses were performed on the standardized residuals after correcting for the effects of age and sex (McGue & Bouchard, 1984).

Table 2 shows twin intraclass correlations (coefficients of twin similarity; Shrout & Fleiss, 1979), along with their 95% confidence intervals, for CHAOS at the two ages and the composite. Inspection of the correlations suggests a modest genetic effect on all measures; MZ twin correlations are greater than DZ twin correlations. However, the DZ twin correlations are greater than half the MZ twin correlations on chaos at both 9 and 12 years, reflected in the derived middle childhood variable ($r_{MZ} = 0.75$, $r_{DZ} = 0.62$), indicating influence of the shared environment. The MZ twin correlations are less than 1 at both age 9 ($r_{MZ} = 0.65$) and 12 ($r_{MZ} = 0.64$) years, indicating that identical twins reared together do not perceive their environment identically.

Univariate genetic analysis of the composite of child-reported chaos at 9 and 12 years is summarised in Table 3. The chi square fit index (and associated p -value, relative to the full ACE model), indicates that a model including all three ACE variance components is the best fitting model. Variation in chaos in the home across middle childhood is largely explained by the shared environment ($C = 0.52$; 95% Confidence Interval (CI) = 0.45 – 0.57), but also has a significant additive genetic component ($A = 0.22$; 95% CI = 0.15 – 0.29). About a quarter of the variance is attributable to nonshared environment, which includes measurement error ($E = 0.26$; 95% CI = 0.24 – 0.29).

Discussion

This is the first study to investigate the environmental and genetic origins of children's perception of noise and confusion in their homes. We observed, first, that even identical twins growing up in the same family experience their environment quite differently. Second, while individual differences in experience of chaos are largely explained by environmental factors that make siblings the same, a latent genetic factor explains 22% of the individual variation in children's experience of the chaotic home. Similar to other measures of the 'environment' (Kendler & Baker, 2007; Plomin & Bergeman, 1991), experience of chaos in the home is partly heritable.

Children in the same home experience chaos differently

Consistent with the finding that both parent and child reports of the home environment indicate that reared-together children can experience the within-family environment quite differently (Daniels et al., 1985), we find that children's reports of their experience of household chaos are different even for identical twins reared together. At least part of the environmental confusion and noise experienced by children growing up in the same home is mediated by environmental factors that they do not share. As MZ twins share 100% of their genes, the differences in experience between them can only be the result of nonshared environments. One potential limitation here is the inclusion of measurement error in the unique environment term. However, our use of a first principal component to measure family chaos from age 9 to 12 meant a reduction in the error term. Similar observations have been made of children's experience of the classroom environment (Asbury, Almeida, Hibell, Harlaar, & Plomin, 2008). For example, even identical twins who share their classroom, teacher, and peers, as well as all of their genes, have different experiences of peer problems, positivity about school, and lesson flow. And these differences of experience are important because they are correlated with their school achievement (Asbury et al., 2008).

While parent reports of chaos in the family home are 'obligatory-shared' because a single parental account describes the chaos experienced by all the children in the home (Purcell & Koenen, 2005), we find differences in children's perceptions of chaos. This finding challenges the view that the home environment acts solely to make reared-together children more alike in either their exposure to, or experience of, chaos. Finding that home environments do not just make children in the same family similar has implications for how we understand the role of the home environment in children's cognitive and behavioral development (Plomin & Daniels, 1987). However, it is perhaps the unobserved factors that contribute to children's similarity in their experience of chaos that are even more provocative – in particular the presence of a genetic component.

Household chaos is heritable

Our findings show that children's perceptions of household chaos are under genetic influence. Different perceptions of the level of chaos in the home are just as likely to reflect some genetically influenced characteristic of the children, as they are to reflect actual

differences in the environment. Selecting or eliciting an environmental experience consistent with one's genes results in an active or evocative GE correlation. Genetic influence on children's cognitive ability, personality, or adaptability for example, may lead to active or reactive (evocative) processes of genetically influenced exposure to the environment. By contrast, a passive GE correlation arises when a child is exposed to an environment consistent with their biological parents' genetic propensities or preferences. The processes by which genetic effects eventuate in exposure to noise and environmental confusion in the home may be a combination of passive, active, and reactive GE correlation. The critical message is that the 'environment' is not independent of the person.

While all three mechanisms of GE correlation are captured by the design of the present study, it may be that non-passive GE correlation (evocative or active) becomes relatively more important than passive GE correlation as the child moves into middle childhood (Scarr & McCartney, 1983). It is conceivable that as children move from early childhood to middle childhood they will not only have more opportunity to express themselves and elicit reactions from people around them, but also take a more active role in directly selecting and modifying the environment. We might imagine that older children have more influence over what time they go to bed, how much television they watch, or how much they contribute to the level of noise and mayhem. In fact, a shift in the mode of genetic influence on children's experience of the environment has been suggested as a potential mechanism by which the observed increase in heritability of complex traits may occur (Bergen, Gardner, & Kendler, 2007; Davis, Haworth & Plomin, 2009; Haworth et al., 2009).

In the present study we chose to combine the child-reports of chaos at the two ages in order to achieve an index of chaos across middle childhood. In future studies, with the additional data we are collecting on the twins in early adolescence, we will be able to use these longitudinal measurements to explore the stability of genetic and environmental components of household chaos. Our next step in the exploration of the chaotic home will be to incorporate child-specific reports of their experience of chaos into multivariate designs along with cognitive and behavioural outcomes in order to establish to what extent the previously observed associations are causal, i.e. truly mediated by the latent environment, and not confounded by genetic effects.

This study adds to a growing literature on GE correlation, and in particular informs our understanding of children's experience of the home environment. The ubiquitous influence of genetics extends beyond the internal environment of the body to affect an individual's surroundings: children's perceptions of the chaotic home environment are shaped by nature, as well as nurture.

Acknowledgments

We gratefully acknowledge the ongoing contribution of the parents and children in the Twins Early Development Study (TEDS). TEDS is supported by a program grant (G0500079) from the UK Medical Research Council; our work on environments and academic achievement is also supported by grants from the US National Institutes of Health (HD44454 and HD46167). CMAH is supported by an MRC/ESRC Interdisciplinary Fellowship (G0802681); OSPD is supported by a Sir Henry Wellcome Fellowship (WT088984).

REFERENCES

- Akaike H. Factor Analysis and AIC. *Psychometrika*. 1987; 52:317–332.
- Asbury K, Almeida D, Hibel J, Harlaar N, Plomin R. Clones in the Classroom: A Daily Diary Study of the Nonshared Environmental Relationship Between Monozygotic Twin Differences in School Experience and Achievement. *Twin Research and Human Genetics*. 2008; 11(6):586–595. doi: 10.1375/twin.11.6.586. [PubMed: 19016614]

- Asbury K, Wachs T, Plomin R. Environmental moderators of genetic influence on verbal and nonverbal abilities in early childhood. *Intelligence*. 2005; 33(6):643–661. doi: 10.1016/j.intell.2005.03.008.
- Bergen SE, Gardner CO, Kendler KS. Age-related changes in heritability of behavioral phenotypes over adolescence and young adulthood: A meta-analysis. *Twin Research and Human Genetics*. 2007; 10(3):423–433. doi: 10.1375/twin.10.3.423. [PubMed: 17564500]
- Coldwell J, Pike A, Dunn J. Household chaos - links with parenting and child behaviour. *Journal of Child Psychology and Psychiatry*. 2006; 47(11):1116–1122. doi: 10.1111/j.1469-7610.2006.01655.x. [PubMed: 17076750]
- Daniels D, Dunn J, Furstenberg FF, Plomin R. Environmental Differences within the Family and Adjustment Differences within Pairs of Adolescent Siblings. *Child Development*. 1985; 56(3):764–774. doi: 10.2307/1129765. [PubMed: 4006577]
- Davis OSP, Haworth CMA, Plomin R. Dramatic increase in heritability of cognitive development from early to middle childhood: An 8-year longitudinal study of 8700 pairs of twins. *Psychological Science*. 2009; 20(10):1301–1308. doi:10.1111/j.1467-9280.2009.02433.x. [PubMed: 19732386]
- Deater-Deckard K, Mullineaux PY, Beekman C, Petrill SA, Schatschneider C, Thompson LA. Conduct problems, IQ, and household chaos: a longitudinal multi-informant study. *Journal of Child Psychology Psychiatry*. 2009; 50(10):1301–1308. doi:10.1111/j.1469-7610.2009.02108.x.
- Dumas JE, Nissley J, Nordstrom A, Smith EP, Prinz RJ, Levine DW. Home Chaos: Sociodemographic, Parenting, Interactional, and Child Correlates. *Journal of Clinical Child and Adolescent Psychology*. 2005; 34(1):93–104. doi: 10.1207/s15374424jccp3401_9. [PubMed: 15677284]
- Evans DM, Gillespie NA, Martin NG. Biometrical genetics. *Biological Psychology*. 2002; 61(1–2):33–51. doi: 10.1016/S0301-0511%2802%2900051-0. [PubMed: 12385668]
- Evans GW. Child development and the physical environment. *Annual Review of Psychology*. 2006; 57:423–451. doi: 10.1146/annurev.psych.57.102904.190057.
- Hart SA, Petrill SA, Deckard KD, Thompson LA. SES and CHAOS as environmental mediators of cognitive ability: A longitudinal genetic analysis. *Intelligence*. 2007; 35(3):233–242. doi: 10.1016/j.intell.2006.08.004. [PubMed: 19319205]
- Haworth CMA, Wright MJ, Luciano M, Martin NG, de Geus EJ, van Beijsterveldt CE, et al. The heritability of general cognitive ability increases linearly from childhood to young adulthood. *Molecular Psychiatry*. 2009 advance online publication 2 June 2009; doi: 10.1038/mp.2009.55.
- Jaffee SR, Price TS. Gene-environment correlations: a review of the evidence and implications for prevention of mental illness. *Molecular Psychiatry*. 2007; 12(5):432–442. doi: 10.1038/sj.mp.4001950. [PubMed: 17453060]
- Johnson AD, Martin A, Brooks-Gunn J, Petrill SA. Order in the House! Associations among Household Chaos, the Home Literacy Environment, Maternal Reading Ability and Children's Early Reading. *Merrill-Palmer Quarterly-Journal of Developmental Psychology*. 2008; 54(4):445–472.
- Kendler KS, Baker JH. Genetic influences on measures of the environment: a systematic review. *Psychological Medicine*. 2007; 37(5):615–626. doi: 10.1017/S0033291706009524. [PubMed: 17176502]
- Matheny AP, Wachs TD, Ludwig JL, Phillips K. Bringing order out of chaos: Psychometric characteristics of the Confusion, Hubbub and Order Scale. *Journal of Applied Developmental Psychology*. 1995; 16:429–444. doi: 10.1016/0193-3973%2895%2990028-4.
- McGue M, Bouchard TJ Jr. Adjustment of twin data for the effects of age and sex. *Behavior Genetics*. 1984; 14(4):325–343. doi: 10.1007/BF01080045. [PubMed: 6542356]
- Neale, MC.; Boker, SM.; Xie, G.; Maes, HM. *Mx: Statistical Modeling*. 6 th ed. VCU Box 900126, Richmond, VA 23298: Department of Psychiatry; 2002.
- Oliver B, Plomin R. Twins Early Development Study (TEDS): A multivariate, longitudinal genetic investigation of language, cognition and behaviour problems from childhood through adolescence. *Twin Research and Human Genetics*. 2007; 10(1):96–105. doi: 10.1375/twin.10.1.96. [PubMed: 17539369]

- Petrill SA, Pike A, Price TS, Plomin R. Chaos in the home and socioeconomic status are associated with cognitive development in early childhood: Environmental mediators identified in a genetic design. *Child Development*. 2004; 32(5):445–460. doi: 10.1016/j.intell.2004.06.010.
- Plomin R, Bergeman CS. The Nature of Nurture: Genetic Influence on “Environmental” Measures. *Behavioral and Brain Sciences*. 1991; 14(3):373–385.
- Plomin R, Daniels D. Why Are Children in the Same Family So Different from One Another. *Behavioral and Brain Sciences*. 1987; 10(1):1–16.
- Plomin R, Defries JC, Loehlin JC. Genotype-Environment Interaction and Correlation in Analysis of Human-Behavior. *Psychological Bulletin*. 1977; 84(2):309–322. doi: 10.1037/0033-2909.84.2.309. [PubMed: 557211]
- Plomin, R.; DeFries, JC.; McClearn, GE.; McGuffin, P. *Behavioral genetics*. 5th Edition. New York: Worth Publishers; 2008.
- Price TS, Freeman B, Craig IW, Petrill SA, Ebersole L, Plomin R. Infant zygosity can be assigned by parental report questionnaire data. *Twin Research*. 2000; 3:129–133. doi: 10.1375/136905200320565391. [PubMed: 11035484]
- Purcell S, Koenen KC. Environmental mediation and the twin design. *Behavior Genetics*. 2005; 35(4): 491–498. doi: 10.1007/s10519-004-1484-9. [PubMed: 15971029]
- Rijsdijk FV, Sham PC. Analytic approaches to twin data using structural equation models. *Briefings in bioinformatics*. 2002; 3(2):119–133. doi: 10.1093/bib/3.2.119. [PubMed: 12139432]
- Scarr S, McCartney K. How people make their own environments: A theory of genotype greater than environmental effects. *Child Development*. 1983; 54:424–435. [PubMed: 6683622]
- Shrout PE, Fleiss J. Intraclass correlations: Uses in assessing rater reliability. *Psychological Bulletin*. 1979; 86(2):420–428. [PubMed: 18839484]
- Trouton A, Spinath FM, Plomin R. Twins Early Development Study (TEDS): A multivariate, longitudinal genetic investigation of language, cognition and behavior problems in childhood. *Twin Research*. 2002; 5(5):444–448. doi: 10.1375/twin.5.5.444. [PubMed: 12537874]

Table 1

Means, standard deviations and analysis of variance by sex and zygosity

CHAOS	Male		Female		MZ		DZ		ANOVA		
	M	SD	M	SD	M	SD	M	SD	Sex	Zyg.	Sex*Zyg. [†] R ² N
9 year	0.07	1.02	-0.07	0.97	-0.01	1.01	0.00	0.99	<0.01	0.97	0.39 0.01 3136
12 year	0.06	0.99	-0.04	1.01	0.01	1.00	0.01	1.00	<0.01	0.68	0.07 0.00 5499
<i>t</i> _{9-12 year}	0.08	1.02	-0.05	1.00	0.01	1.02	0.00	1.01	<0.01	0.62	0.23 0.01 2489

M = mean; SD = standard deviation; MZ = monozygotic twins; DZ = dizygotic twins; Sex = *p*-value associated with sex effect on means; Zyg. = *p*-value associated with effect of zygosity on means; R2 = proportion of the total variance explained by sex and zygosity; ANOVA = Analysis of variance performed using one member of each twin pair; N = number of randomly selected individuals (1 member of each twin pair) included in ANOVA analysis

[†] First principle component composite of CHAOS at age 9 and 12

Table 2

Twin intra-class correlations

CHAOS	MZ	N	DZ	N	Total N
9 year	0.65 (0.62 – 0.67)	1112	0.52 (0.48 – 0.55)	1878	2990
12 year	0.64 (0.61 – 0.66)	1935	0.56 (0.53 – 0.58)	3449	5384
[†] 9–12 year	0.75 (0.72 – 0.77)	877	0.62 (0.59 – 0.65)	1460	[*] 2337

MZ = monozygotic twins; N = number of complete twin pairs; DZ = dizygotic twins; 95% confidence intervals shown in parentheses

[†] First principle component composite of CHAOS at age 9 and 12

^{*} 2337 complete twin pairs (out of the 4956 individuals with data at both ages who were all included in the more comprehensive structural equation modelling analyses).

Table 3

Univariate genetic analysis

Measure	Model	Model Fit				
		-2LL	df	$\Delta\chi^2$	AIC	Δdf p
[†] CHAOS 9–12 year	Sat	12634.01	4946	-	2742.01	- -
	* ACE	12637.38	4949	3.37	2739.38	3 0.34
	CE	12670.85	4950	33.47	31.47	1 <0.01
	AE	12811.42	4950	174.04	172.04	1 <0.01

-2LL = negative 2 log likelihood; df = degrees of freedom; $\Delta\chi^2$ = difference in chi square; AIC = Akaike's Information Criterion; Δdf = difference in degrees of freedom; p = p-value; Sat = saturated model with means and variances constrained across sex

[†] First principle component composite of CHAOS at age 9 and 12

* Fit of nested models CE and AE given relative to full ACE model