J. Intell. **2015**, *3*, 160-167; doi:10.3390/jintelligence3040160

OPEN ACCESS

Journal of

Intelligence

ISSN 2079-3200

www.mdpi.com/journal/jintelligence

Brief Report

Phenotypic, Genetic, and Environmental Correlations between Reaction Times and Intelligence in Young Twin Children

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Academic Editor: Oliver Wilhelm

Received: 20 May 2015 / Accepted: 11 December 2015 / Published: 17 December 2015

Abstract: Phenotypic, genetic, and environmental correlations between various reaction time measures and intelligence were examined in a sample of six-year-old twin children (*N* = 530 individuals). Univariate genetic analyses conducted on the same-sex pairs (101 monozygotic (MZ) pairs and 132 same-sex dizygotic (DZ) pairs) demonstrated that the intelligence measure and four of the seven reaction time measures had a genetic component (ranging from 44% to 76%). At the phenotypic level, half of the reaction time measures had significant negative correlations with the intelligence measure. Bivariate genetic analyses revealed that only two of the observed phenotypic correlations could be explained by common genetic factors and that the remaining correlations were better explained by common environmental factors.

Keywords: intelligence; ability; twins; behaviour genetics

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1. Introduction

Reaction time tests measure speed of information processing by combining physical and perceptual responses. In general, the participant is required to respond as fast as possible, by pressing a response button, to a visually presented question. In a review of the speed of information processing and intelligence literature over 50 years, Sheppard and Vernon [1] reported that the average correlation between reaction time measures and general intelligence was −0.26 (based on 172 studies reviewed) and ranged from −0.22 to −0.40. Age trends were also examined in the review and a curvilinear relationship between age and speed of information processing was reported in which young children and older adults were found to be slower than adults. Also reviewed were 13 behavior genetic studies. The average heritability estimate of speed of information processing tests (which included a range of measures such as reaction time, inspection time, short term memory, and speeded tests of long term memory) was reported to be 48% with an average genetic correlation with intelligence of −0.73 [1].

Typically studies examining the relationship between reaction time and intelligence are conducted with adult participants (see [1]), although some have examined adolescents [2,3] and others have looked at young twins with clinical issues such as attention deficit hyperactivity disorder [4]. Four notable studies, however, were conducted on young children. DiLalla *et al.* [5] examined infants' (seven to nine month old) response time to a visual stimulus. The test involved using eye movements to assess the speed to which the infant would predict the location of a visual object. Also assessed was the infant's intelligence using a standardized test. The correlation found was −0.20 between the response time measure and intelligence scores. Petrill, Luo, Thompson and Detterman [6] demonstrated that mental speed tests (including reaction time) were correlated with general intelligence, but also had significant genetic variance unrelated to general intelligence in a sample of twins between 6 and 13 years old. Ho, Baker, and Decker [7] examined the relationship between a symbol processing speed factor (based on two tests assessing the speed in which individuals could rotate number and letters) and intelligence in a sample of children aged 8 to 18 years with a reported correlation of −0.418. Miller and Vernon [8] examined the correlations between reaction time and intelligence in children between the ages of four and six years. Using a weighted linear aggregate (based on Principal Components factor loadings) of multiple reaction time measures, the correlation with intelligence was found to be −0.419.

The present study was designed to further explore the relationships between measured intelligence and performance on reaction time measures at both the phenotypic (observed zero-order correlations) and at the genetic and environmental levels (following bivariate modelling). Analyses were conducted on data collected from six-year-old twins. Seven of the reaction time tests used in the Miller and Vernon [8] study were examined with the aim of trying to replicate the correlations between reaction time and intelligence. Because the present sample included twins, univariate genetic analyses were also examined to calculate estimates of the percentage of variance due to genetic and environmental factors. In addition, bivariate genetic analyses assessed if any of the phenotypic correlations may be due to common genetic and/or environmental factors. The general goals of the analyses were to expand on the relationships found with speed of information processing and measured intelligence.

2. Method

2.1. Participants

Participants were 265 pairs of six-year-old twins, comprising 34 pairs of monozygotic (MZ) male twins, 43 pairs of MZ female twins, 55 pairs of dizygotic (DZ) male twins, 47 pairs of DZ female twins, and 86 pairs of opposite-sex DZ twins. In the analyses presented in the following results section, data from all individuals were used in the phenotypic analyses, while data from only the same-sex MZ and DZ pairs were used in the univariate and bivariate behavior genetic analyses. The twins were recruited via newspaper advertisements and through contacts with local Parents of Multiple Birth Associations in London, Ontario and Vancouver, British Columbia, Canada.

2.2. Materials

The twins' intelligence was measured with the Raven Coloured Progressive Matrices [9], which has been reported to be reliable for participants assessed at age 6 [10].

The twins were also given a battery of seven computer-administered reaction time (RT) tests to assess speed of information processing and were based on the tests used by Miller and Vernon [8]. In each of the non-verbal RT tests, the children saw two geometrical stimuli, which varied in colour and size, and had to indicate as quickly as they could (by pressing one of two buttons on a response console) whether the stimuli were the same or different. In the first test (Size) the stimuli (identical shapes) were either the same or a different size. Three different shapes were used, including triangles, squares, and octagons and these shapes were presented in either red or yellow. In the second test (Shape), the stimuli (triangles, squares, octagons, and diamonds) were either the same or were different shapes. In the third test (Arrow), the child was required to respond by pressing the left or right key to indicate the direction of the arrow. In the fourth test (Colour), the child is required to indicate if the two shapes (triangles and squares) were either the same or a different colour.

The fifth reaction time test (Number) involved the presentation of two columns of shapes and the child is required to respond if the same number of shapes appeared in each column or not. Colour was varied across trials but not within the trial. In the sixth test (Find Colour), the child is first presented with a colour followed by a string of colours (all of the same shape) and the child is asked to respond whether or not the first colour appears in the string of colours. The seventh test (Find Shape) is the reverse of the Find Colour test in that the child is presented a shape of a certain colour and is then presented with a string of shapes (all the same colour as the target shape) and is asked if the initial shape was present in the string. As in the Miller and Vernon [8] study, the children were given six practice trails and a tone was used to indicate correct versus incorrect responses. For each of the individual tests, the mean score was calculated over 24 trials.

2.3. Procedure

Two research assistants (RAs) visited the twins in their homes. In both London and in Vancouver, one of the RAs was a trained psychometrist who administered (and scored) the Raven according to the directions in the manual and the other RA was a Psychology undergraduate student who administered the other tests. After receiving informed consent from the twins' caregiver, one RA tested one twin while the other RA tested the second twin in a separate room. When each RA completed their testing, they gave the twins a short break and then resumed testing with the other twin. Total testing time for both twins was approximately two hours.

3. Result

3.1. Sex Differences in Reaction Time and Intelligence Scores

Sex differences were examined for the intelligence and reaction time (RT) scores. For the test of mean differences (t-test), no significant sex differences were found. In terms of variance differences (F-test), males were more variable on the arrow ($F = 5.47$, $p < 0.01$) and the color ($F = 4.22$, $p < 0.05$) RT scores. Also computed was Cohen's d-statistic to measure the effect size of the differences. All of the effect size values were small.

3.2. Reaction Time Tests Factor

Similar to the method employed by Miller and Vernon [8], a Principal Components Analysis was conducted on the seven reaction time means. A single factor was extracted accounting for 76.16% of the variance. The factor loadings for the individual tests were: 0.93 size, 0.83 shape, 0.88 arrow, 0.91 colour, 0.92 number, 0.87 find colour, and 0.76 find shape. These factor loadings were then used as weights in generating weighted linear aggregate factor scores.

3.3. Univariate Genetic Analyses of Reaction Time and Intelligence Scores

Within-twin-pair correlations were computed for the reaction time means and the Ravens scores. These correlations are reported in Table 1 and demonstrate, for the majority of the measures, higher within-twin-pair correlations for the MZ twins than the DZ twins. Univariate genetic analyses were conducted on the within-twin-pair variance-covariance matrices using the program Mx [11], a matrix-based structural equation program designed for twin models. In these analyses, the phenotypic score is expressed as a linear function of three factors: genetic (A), common environment (C), and unique environment (E). In conducting univariate genetic analyses, four models are tested (a full ACE model, an AE model, a CE model, and an E only model) and the model which has the best fit to the data (lowest chi-square per degree of freedom and lowest Akaike's Information Criterion (AIC) value), and which is the most parsimonious, is the model chosen as the best fitting model [12]. Once the best fitting model is decided, heritability (a^2), common environment (c^2), and unique environment (e^2) values are computed from the standardized parameter estimates. The results of the univariate genetic analyses are listed in Table 1.

The Raven intelligence score, the size, the arrow, the number, and the find shape reaction time scores were found to be best fit by an AE model, with heritability estimates ranging from 44% to 76%. The model with C and E effects only was found to be the best fitting model for the remaining reaction time measures and for the reaction time factor score with C effects ranging from 48% to 75%. None of the measures was best fit by an E-only model.

Table 1. MZ and DZ correlations and results of univariate genetic analyses.

Variable	MZ*r*	DZ*r*	a^2 (95% C.I.)	c^2 (95% C.I.)	e^2 (95% C.I.)	AIC
Raven	0.62 **	0.42 **	0.40 (0.00 to 0.76)	0.22 (0.00 to 0.61)	0.38 (0.24 to 0.61)	−4.22
			0.64 (0.45 to 0.77)	–	0.36 (0.23 to 0.55)	−5.48
Size RT	0.70 **	0.52 *	0.57 (0.00 to 0.87)	0.18 (0.00 to 0.66)	0.25 (0.13 to 0.51)	−2.81
			0.76 (0.34 to 0.87)	–	0.24 (0.13 to 0.46)	−4.47
Shape RT	0.52 *	0.58 **	0.00 (0.00 to 0.60)	0.54 (0.00 to 0.71)	0.46 (0.28 to 0.71)	−2.46
			–	0.54 (0.29 to 0.72)	0.46 (0.28 to 0.71)	−4.46
Arrow RT	0.64 **	0.40	0.69 (0.00 to 0.84)	0.00 (0.00 to 0.57)	0.31 (0.16 to 0.62)	−1.63
			0.69 (0.41 to 0.84)	–	0.31 (0.16 to 0.59)	−3.63
Colour RT	0.53 **	0.48 *	0.11 (0.00 to 0.72)	0.40 (0.00 to 0.67)	0.49 (0.26 to 0.77)	−0.15
			–	0.48 (0.22 to 0.68)	0.52 (0.32 to 0.78)	−2.09
Number RT	0.74 **	0.58 **	0.41 (0.00 to 0.77)	0.33 (0.00 to 0.84)	0.26 (0.14 to 0.50)	−4.02
			0.47 (0.36 to 0.90)	–	0.53 (0.10 to 0.64)	−4.41
Find Colour RT	0.59 **	0.53 **	0.10 (0.00 to 0.71)	0.46 (0.00 to 0.71)	0.44 (0.24 to 0.71)	−0.27
			–	0.53 (0.29 to 0.71)	0.47 (0.29 to 0.71)	−2.20
Find Shape RT	0.72 **	0.45 *	0.41 (0.00 to 0.82)	0.28 (0.00 to 0.73)	0.31 (0.17 to 0.57)	−5.12
			0.44 (0.31 to 0.87)	–	0.56 (0.13 to 0.69)	−6.56
Reaction Time Factor	0.85 **	0.63 **	0.20 (0.00 to 0.51)	0.60 (0.30 to 0.79)	0.20 (0.14 to 0.34)	−2.60
			–	0.75 (0.66 to 0.82)	0.25 (0.18 to 0.34)	−3.17

* $p < 0.05$; ** $p < 0.01$, two-tailed; full ACE results are reported in the first line, followed by the better fitting reduced model estimates (if applicable) based on the lowest AIC value; C.I. = confidence Interval.

3.4. Phenotypic Correlations between Intelligence and Reaction Time Measures

Presented in Table 2 are the phenotypic (observed) correlations between the intelligence scores and the reaction time measures for the entire sample. Significant negative correlations were found between the Raven test scores and half of the reaction time measures, with the strongest correlations with the Number and Find Colour tests.

3.5. Genetic and Environmental Correlations between Reaction Time and Intelligence

Bivariate genetic analyses were performed using Mx [11] to further examine the covariance between each of the intelligence and reaction time scores. Cholesky or triangular decomposition (see [12]) was applied to the MZ and DZ mean square between- and within-pair covariance matrices to calculate genetic and environmental correlations. In particular, one twin's intelligence test score was correlated with their co-twin's RT score. If the cross-correlations are higher for the MZ twins compared to the DZ twins, the influence of common genetic factors is suggested. An ACE, an AE, a CE, and E-only models were computed where A represents genetic covariation, C common environment covariation, and E unique environment covariation. In each of the analyses, an AE or CE model was found to have the best fit to the data. These results suggest that genetic and common environmental factors cannot be omitted from the models.

Table 2 lists the results of the bivariate genetic analyses. Only two of the reaction time scores (Arrow and Find Shape) were found to be best fit by an AE model suggesting that the phenotypic correlation observed could be due somewhat to common genetic factors, although each of the genetic correlations included zero in their 95% confidence intervals. Similar results were found for the common and unique environmental correlations computed; again suggesting that the phenotypic correlations can be explained somewhat by common environmental overlap, but again the results should be interpreted with caution because the 95% confidence intervals do include zeros.

Table 2. Phenotypic, Genetic, and Environmental Correlations between Ravens and Reaction Time Measures.

Reaction Time Test	*r*p	*r*g	*r*c	*r*e
Size	−0.09	–	−0.36 (−0.69 to 0.06)	−0.16 (−0.46 to 0.16)
Shape	−0.09	–	−0.31 (−0.72 to 0.18)	−0.15 (−0.44 to 0.18)
Arrow	−0.11 *	−0.29 (−0.63 to 0.09)	–	−0.18 (−0.55 to 0.26)
Colour	−0.08	–	−0.22 (−0.64 to 0.26)	−0.04 (−0.35 to 0.28)
Number	−0.26 **	–	−0.29 (−0.65 to 0.14)	−0.05 (−0.36 to 0.27)
Find Colour	−0.23 **	–	−0.25 (−0.68 to 0.23)	0.02 (−0.30 to 0.33)
Find Shape	−0.21 *	−0.18 (−0.59 to 0.22)	–	−0.03 (−0.24 to 0.37)
RT Factor	−0.05	–	−0.02 (−0.23 to 0.20)	−0.18 (−0.35 to −0.01)

* $p < 0.05$; ** $p < 0.01$ (two-tailed); *r*p = phenotypic correlation; *r*g = Genetic correlation; *r*c = Common environment correlation; *r*e = Unique environmental correlation. Values in brackets represent the 95% confidence interval.

4. Discussion

The present study was designed to further investigate the relationship between reaction times and measured intelligence by computing phenotypic (observed), genetic, and environmental correlations. Twin children completed seven reaction time measures. The mean values as well as a reaction time factor score were examined for their relationship with measured intelligence. Univariate genetic analyses conducted on the same-sex twin pairs demonstrated that the intelligence measure and four of the seven reaction time measures had a genetic component (ranging from 44% to 76%). The remaining tests and the reaction time factor score were found to be best fit by common and unique environmental models with common environment effects ranging from 48% to 75% for the reaction time factor score. These values seem to fit within the range reported in the review by Sheppard and Vernon [1] (2008) who reported, across multiple speed of information processing measures, heritability values ranging from 0 to 90% with a sample size weighted average of 48%.

At the phenotypic level, half of the reaction time measures had significant negative correlations with the intelligence measure. In general the values were lower than those reported in previous studies using younger samples but some of the correlations were similar to the −0.20 value reported by DiLalla *et al.* [5]. The finding of robust correlations of −0.40 by [7,8] between a reaction time factor and intelligence was not replicated in the present study. This failure to replicate may be due to the different measures used in the Ho *et al.* [7] study but the seven reaction time measures used in the present study were directly adapted from the Miller and Vernon [8] study. The inconsistent results suggest that further studies are required examining both individual reaction time tests as well as factor scores with intelligence in children.

Bivariate genetic analyses revealed that some of the observed phenotypic correlations may be explained by common genetic and/or environmental factors, but the confidence intervals suggested that the genetic and common environmental factors were not highly significant. The genetic correlations estimated in the present study are lower in value compared to those typically reported (see review [1]). The lower values found in the present study may reflect some of the genetic variance in the reaction time measures which is not common with measured intelligence, a finding reported in an earlier twin study by Petrill *et al.* [6]. Future research may want to examine larger twin samples as well as various reaction time measures and possibly different intelligence tests.

Author Contributions

Julie Aitken Schermer conducted the analyses and wrote the manuscript. Philip A. Vernon secured the research funding for the study, interviewed and hired research assistants to collect the data, and contributed to writing the article

Conflicts of Interest

The authors declare no conflict of interest.

References

1. Sheppard, L.D.; Vernon, P.A. Intelligence and speed of information-processing: A review of 50 years of research. *Pers. Individ. Differ.* **2008**, *44*, 535–551.
2. Hansell, N.K.; Wright, M.J.; Luciano, M.; Geffen, G.M.; Geffen, L.B.; Martin, N.G. Genetic covariation between even-related potential (ERP) and behavioral non-ERP measures of working-memory, processing speed, and IQ. *Behav. Genet.* **2005**, *35*, 695–706.
3. Luciano, M.; Smith, G.A.; Wright, M.J.; Geffen, G.M.; Geffen, L.B.; Martin, N.G. On the heritability of inspection time and its covariance with IQ: A twin study. *Intelligence* **2001**, *29*, 443–457.
4. Kuntsi, J.; Pinto, R.; Price, T.S.; van der Meere, J.J.; Frazier-Wood, A.C.; Asherson, P. The separation of ADHD inattention and hyperactivity-impulsivity symptoms: Pathways from genetic effects to cognitive impairments and symptoms. *J. Abnorm. Child Psychol.* **2014**, *42*, 127–136.
5. DiLalla, L.F.; Thompson, L.A.; Plomin, R.; Philips, K.; Fagan, J.F.; Haith, M.M.; Cyphers, L.H.; Fulker, D.W. Infant predictors of preschool and adult IQ: A study of infant twins and their parents. *Dev. Psychol.* **1990**, *26*, 759–769.
6. Petrill, S.A.; Luo, D.; Thompson, L.A.; Detterman, D.K. The independent prediction of general intelligence by elementary cognitive tasks: Genetic and environmental influences. *Behav. Genet.* **1996**, *26*, 135–147.
7. Ho, H.; Baker, L.A.; Decker, S.N. Covariation between intelligence and speed of cognitive processing: Genetic and environmental influences. *Behav. Genet.* **1988**, *18*, 247–261.
8. Miller, L.T.; Vernon, P.A. Intelligence, reaction time, and working memory in 4- to 6-year old children. *Intelligence* **1996**, *22*, 155–190.

9. Raven, J.C. *Guide to Using the Colored Progressive Matrices Sets A, Ab, and B*; H.K. Lewis: London, UK, 1965.
10. Carlson, J.S.; Jensen, C.M. Reliability of the raven colored progressive matrices test: Age and ethnic group comparisons. *J. Consult. Clin. Psychol.* **1981**, *49*, 320–322.
11. Neale, M.C. Mx: *Statistical Modeling Manual*, 4th ed.; University of Virginia: Charlottesville, VA, USA, 1997.
12. Neale, M.C.; Cardon, L.R. *Methodology for Genetic Studies of Twins and Families*; Springer Science & Business Media: Berlin, Germany, 1992.