Published in final edited form as:
Pers Individ Dif. 2007 May ; 42(7): 1209–1219.

Intellectual similarity of virtual twin pairs: Developmental trends

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Abstract

Virtual twins (VTs) are same-age unrelated siblings reared together from infancy who replicate twinship, but without the genetic relatedness. A 2005 report from the ongoing Fullerton Virtual Twin Study found an IQ intraclass correlation of .26 ($p < .01$, $n = 113$ pairs) and a within-pair difference of 13.22 IQ points. The average age of VTs in that study was 8.10 years (SD = 8.56, range: 4.01–54.84 years). An opportunity to retest members of 43 VT pairs, 1.70–8.96 years after their time 1 assessment, allowed additional analyses of genetic and environmental influences underlying general intellectual development. A decrease in the VT IQ correlation and an increase in the within-pair difference were indicated, consistent with increasing genetic and/or non-shared environmental influences and decreasing shared environmental influence on general intellectual development throughout childhood.

Keywords

Twins; Virtual twins; Intelligence

1. Introduction

Virtual twins (VTs) are same-age, unrelated siblings reared together since infancy. They replicate the rearing situation of twins, offering an opportunity to directly assess shared environmental effects on developmental traits. VT pairs are composed of either two adopted children, or one adoptee and one biological child. Research advantages of VTs, compared with ordinary adoptive siblings, is that members of VTs are the same age and share residential histories (Segal, 2000a, 2005).

A series of reports from the ongoing Fullerton Virtual Twin Study found that VTs show modest similarity in general intelligence and negligible similarity in their mental ability profile (Segal, 1997, 2000b; Segal & Hershberger, 2005), consistent with genetic influence and modest shared environmental effects. In a combined twin and virtual twin analysis, evidence of both genetic and shared environmental influences on body size was found (Segal & Allison, 2002).

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Additional information about the project is available in Segal (2000a, 2005) and in references cited therein.

The Twins, Adoptees, Peers and Siblings (TAPS) project, launched in 2002, is a collaborative research effort between California State University, Fullerton and the University of San Francisco (McGuire & Segal, 2005). Genetic and environmental influences on general intelligence, social relations and behavioral adjustment are assessed via multiple measures completed by pairs of 8–13-year-old MZ twins, DZ twins, full siblings, virtual twins and best friends. TAPS provided an opportunity to administer a general intelligence test to a subsample of VT pairs several years after their initial participation (time 1) in the Fullerton study.

The extent to which VTs would maintain the modest IQ similarity observed in early childhood was of interest. Previous adoptive sibling studies have reported decreasing IQ resemblance as development proceeds. Loehlin, Horn, and Willerman (1989) found that the IQ correlation for pairs of 8-year-old adoptive siblings declined from .26 to near zero when they were reassessed 10 years later. This same trend was observed in a subsequent adoption study (Scarr, Weinberg, & Waldman, 1993) and in a summary of seven adoption studies (McGue, Bouchard, Iacono, & Lykken, 1993). Collectively, this research shows that shared home environmental effects on intelligence wane as siblings age.

Consistent with this finding, longitudinal twin and family studies and studies of older twins show that genetic effects on general intelligence increase over time (McClearn et al., 1997; Plomin, Fulker, Corley, & DeFries, 1997; Wilson, 1983). It has also been shown that environmental influences on mental development beyond childhood appear to be those that are not shared by family members. It is estimated that between childhood and adulthood, genetic influence on intelligence increases from 40% to 60%, non-shared environmental influence increases from 25% to 35% and shared environmental influence decreases from 25% to near zero (Plomin, DeFries, McClearn, & McGuffin, 2001).

Relative to ordinary adoptive siblings, VTs offer a more sensitive test of shared environmental contributions to mental development. Specifically, most unrelated siblings are not matched in age and typically join their families at different time points. Siblings' age differences were not reported by Loehlin et al. or by Scarr et al.; however, adoptees in those studies ranged in age from 3 to 14 years, and from 4 to 10 years, respectively, at their initial testing. Some biological children in the Scarr et al. study were older than 16 years of age. It is, therefore, likely that the unrelated siblings in these studies had different educational experiences, both at home and at school. In contrast, members of VT pairs are the same age so are likely to have had many, if not most, educational and instructional experiences in common.

2. Method

2.1. Research design and procedures

VT pairs are defined by a strict set of guidelines: (1) Adoption by one year of age. (2) Sibling age difference of nine months, or less. (3) Enrollment of siblings in the same school grade. (4) Absence of birth events adversely affecting mental development. (5) Current age of four years, or older. Both same-sex and opposite-sex siblings are studied, given that DZ twins may be same-sex or opposite-sex. Siblings with different ethnic backgrounds are also studied because DZ twins born to interracial couples may appear quite different physically (Segal, 2000b).

Families with virtual twins are located throughout the United States and Canada via personal referrals, twins clubs, the media and other sources. Parents receive background questionnaires, personality inventories and other forms to complete and return by mail. Local examiners, who are not associated with the Fullerton Virtual Twin Study and who are blind to the hypotheses, are hired to administer the complete age-appropriate version of the Wechsler Intelligence test to each child (time 1). Pair members in the present study were tested on the same day (with one exception) and by different examiners (with two exceptions). All protocols were reviewed for scoring accuracy upon receipt.

At retest, all but two VT pairs completed the Information, Vocabulary, Block Design and Picture Arrangement subtests from the Wechsler Intelligence Scale for Children-III (WISC-III) (time 2). The IQ score is calculated by first converting raw scores to scaled scores. The two verbal scaled scores and the two non-verbal scaled scores are added and each sum is multiplied by 5/2.Verbal IQ, Performance IQ and Full Scale IQ scores are derived from tables in the test manual. These four subtests have been administered to twin participants in previous developmental studies of intelligence (McGue et al., 1993). The composite score yielded by this subtest combination correlates higher than .90 with the full scale IQ score (Sattler, 1989). Two other VT pairs completed all subtests of the WISC-III at time 2. All siblings were tested on the same day, and in all but two cases were tested by different examiners.

2.2. Research participants

The present follow-up assessment included 43 VT pairs identified initially through the Fullerton study. Forty-one pairs were retested as part of the TAPS project. These pairs were recruited by TAPS because they were between the specified ages of 8 and 13 years; however, three children of age 7 years were included. Parents of qualified pairs were contacted by telephone and asked to participate in this second, comprehensive child development study. Two VT pairs included in the present follow-up study were retested prior to the start of TAPS. Of the contacted pairs, 86% agreed to participate.

Seventy children completed the WPPSI-R, twelve children completed the WISC-III and two children completed the WPPSI at time 1. Thus, only 12 of the 84 children completed the WISC-III at both time 1 and time 2. One child with unrelated triplet siblings was part of three VT pairs, but was counted only once in individual analyses.

The mean age at testing at time 1 for the 43 VT pairs was 5.11 years (SD = 1.10), and the mean age at time 2 was 10.77 years (SD = 1.61). The mean interval between IQ testing at time 1 and time 2 was 5.65 years (SD = 1.58), and ranged between 1.70 and 8.96 years. The sample included 30 adoptive–adoptive pairs and 13 biological–adoptive pairs. Nine pairs were male–male, nine pairs were female–female and 25 pairs were male–female.

The majority of children were Caucasian (62%), while the remaining children were Black (6%), Asian (2%), Hispanic (11%), South American Indian (3%) or Mixed (16%). At time 1, 29 pairs (67%) were in the same class, 11 pairs (26%) were in different classes and three pairs (7%) were not attending school. At time 2, 12 pairs (28%) were in the same class at school and 31 pairs (72%) were in different classes. Forty pairs (93%) were still in the same grade, while three pairs were in different grades (7%). Additional descriptive information is provided in Table 1.

3. Results

IQ findings for VTs at the time 1 and time 2 test sessions are presented in Tables 2 and 3. The mean IQ score was 105.86 (SD = 11.41) at time 1 and 108.89 (SD = 13.25) at time 2, a difference that was statistically significant [$t(83) = -2.25$, $p < .05$]. Mean IQ scores at time 1 for the original 2005 sample ($n = 221$) and the subset of siblings ($n = 84$) in the present study were nearly identical. The same pattern was observed for Verbal IQ. The mean Verbal IQ score was 105.27 (SD = 12.28) at time 1 and 109.64 (SD = 12.62) at time 2, a difference that was statistically significant [$t(83) = -3.36$, $p < .001$]. Mean Verbal IQ scores at time 1 for the 2005 sample and the present subset of siblings did not differ. Mean Performance IQ scores did not differ between time 1 and time 2, or between participants in the original and present samples.

Test correlations between time 1 and time 2 were .50 ($p < .01$) for Full Scale IQ, .54 for Verbal IQ, and .42 ($p < .01$) for Performance IQ. The Full Scale IQ test–retest correlation was slightly lower than those reported for samples of biological children ($r = .62$, $n = 104$), Caucasian adoptees ($r = .63$, $n = 16$), Asian/Indian adoptees ($r = .62$, $n = 12$) and Black/Interracial adoptees ($r = .57$, $n = 101$), for tests taken at mean ages of 7–8 years and 17–18 years (Scarr et al., 1993; Weinberg, Scarr, & Waldman, 1992). The interval between testing at time 1 and time 2 was not associated with IQ score at time 2, nor was it associated with the absolute difference in IQ scores at time 1 and time 2.

VT Full Scale IQ intraclass correlations at time 1 and time 2 were .30 ($p < .05$) and .11, respectively. Intraclass correlations for Verbal IQ at time 1 and time 2 were .24 and .17; and intraclass correlations for Performance IQ at time 1 and time 2 were .27 ($p < .05$) and .06. Intraclass correlations for the 2005 sample are provided for comparison. Mean within-pair IQ differences for the 43 VT pairs at time 1 and time 2 were 10.74 (SD = 8.31) and 14.12 (SD = 10.39), respectively, a difference that was statistically significant [$t(42) = -2.03$, $p < .05$]. The time 2 value is larger than those reported for MZ (6.43, SD = 5.52) and DZ (10.60, SD = 9.98) child pairs (Segal, 1985), but equal to or slightly smaller than those of full siblings (14), unrelated individuals living together (15) and unrelated individuals selected at random (17 points) (Plomin & DeFries, 1980). A significant VT within-pair difference was also found for Performance IQ [$t(42) = -3.41$, $p < .001$]. All within-pair difference scores were significantly lower for VTs participating at time 2, relative to VTs in the 2005 sample.

The correlation between IQ and rearing status (biological or adoptive) was not statistically significant at time 1, but was statistically significant at time 2 (.26, $p < .05$). Verbal IQ and Performance IQ scores showed the same pattern (higher at time 2), although the correlation was significant for Performance IQ only. Biological children significantly outperformed non-biological children. This pattern was replicated using scores from the 13 biological–adoptive pairs only, but owing to the small sample size the differences were not statistically significant. The previous analysis by Segal and Hershberger (2005) found that rearing status correlated significantly with Full Scale IQ, Verbal IQ and Performance IQ, but the sample size was larger (n[individuals] = 221) and participant age was more varied (4.01–54.84 years).

It is worth noting that the Full Scale IQ score increase was higher for the biological children than for the adoptive children. The difference was, however, significant for Performance IQ only. These data are summarized in Table 4.

Several background variables correlated significantly with the IQ data at the individual level. These data are summarized in Table 5a. Time 1: earlier age at adoption (or hospital release for biological children) was associated with higher IQ and higher Verbal IQ scores. Older age at testing was associated with a higher Performance IQ score. Time 2: membership in a biological–adoptive pair and fewer pre-adoption placements were associated with a higher IQ score. Younger age at adoption was associated with a higher Verbal IQ score.

Several background variables correlated significantly with the IQ data at the pair level. Time 1: matched ethnicity was associated with larger Full Scale IQ and Performance IQ score differences. Attending the same class was associated with a smaller Verbal IQ difference, as was a higher percentage of shared classes. Time 2: membership in a biological–adoptive pair was associated with a larger IQ difference, as was enrollment in the same class at testing. These data are summarized in Table 5b.

4. Discussion

The 43 VT pairs in the follow-up group showed a three-point increase in IQ score between testing at time 1 and time 2, a difference that was statistically significant. This may be partly explained by the substantial percentage of children age 5 years and younger at time 1 (72%), below the age at which IQ stability is typically achieved (Berk, 2006). The Verbal IQ score, but not the Performance IQ score, showed a similar increase.

The Full Scale IQ and Performance IQ correlations were modest but significant at time 1, most likely reflecting shared rearing effects. The Verbal IQ correlation was similar in magnitude, but non-significant. However, the correlations for IQ and performance IQ decreased substantially at time 2, consistent with decreasing shared environmental influence and increasing genetic and/or non-shared environmental influences on general mental skills during development. (Decreases in the magnitude of the correlations were not significant, owing to the small sample size.) The Verbal IQ correlation decreased less than the Full Scale and Performance IQ correlations, suggesting some shared environmental effects; however, the time 1 verbal IQ correlation was not significant.

The within-pair differences in all three IQ scores also increased, although the differences were significant for the Full Scale IQ and Performance IQ scores only. The Full Scale IQ within-pair difference at time 2 (14.12) exceeded the values reported for MZ and DZ twin children (6.43 and 10.06, respectively), and approached those of unrelated individuals living together and unrelated individuals chosen randomly. These findings also suggest decreasing effects of the shared environment and/or accumulating effects of genetic and non-shared environmental influences on mental ability during development.

Test scores at time 1 correlated significantly with test scores at time 2, but the correlations (.42–.54) were below those reported in the test manual for the different versions of the test (WPPSI-R, WISC-III: Full Scale IQ: .85; Verbal IQ: .85; Performance IQ: .73; Wechsler, 1991). This could be due partly to the administration of an abbreviated test form at time 2 and/or the longer test interval for present participants (1.70–8.96 years) than for participants in Wechsler's sample (12–62 days). In addition, only 12 of the 84 children completed the WISC-III on both occasions. Test–retest correlations (.57–.63), reported by Scarr et al. (1993) and also based on abbreviated forms of the WISC-R and WAIS-R, were below the values reported in the test manual (WISC-R, WAIS-R: Full Scale IQ: .88; Verbal IQ: .89; Performance IQ: .76; Wechsler, 1981). The lower test–retest correlations for VTs than for children in the Scarr et al. study may partly reflect the VTs' younger age at participation.

The higher IQ scores and larger IQ gains obtained by biological children than by adoptive children are consistent with previous reports from this study, and with extant studies (see Cardon, 1994; Dumaret & Stewart, 1985). The VTs' parents generally held professional, technical or managerial positions or, if not employed outside the home, had earned higher educational degrees. Thus, their biological children stood to benefit from both their parents' genes and environments. Specifically, it is possible that the environments of the biological children were more compatible with their genetically influenced abilities than were those of the adopted children, allowing better expression and development of their abilities.

In contrast, it is likely that the adoptive children came from more varied biological backgrounds. As such, these children may not have experienced the same degree of gene-environment correlation in their rearing homes as did the biological children. It cannot be known for certain what the IQ scores of the adoptees would have been had they not been adopted, but they might have been somewhat lower. IQ gains as large as 19.5 have been found among children adopted by high SES families at ages 4–6 and who had experienced abuse or neglect (Duyme, Dumaret, & Tomkiewcz, 1999). A recent meta-analysis showed that adopted children's IQ scores exceeded those of their non-adopted biological siblings and peers who remained with their birth families or in institutional care (Van Ijzendoorn, Juffer, & Poelhuis, 2005). The adopted children's scores did not differ from those of their non-adopted siblings (the children with whom they were raised) or their peers. However, the adopted children showed poorer language skills and received more frequent special education referrals than the non-adopted children. Some of the adoptive children in the present study were just approaching middle childhood, so it is possible that larger IQ gains might be detected at a later date. However, this possibility does not discount the evidence for genetic and non-shared environmental effects on mental development.

Children adopted or released from the hospital at younger ages may be healthier than those adopted or released later. This may explain the negative association between age entering the family and test performance. A higher number of living situations prior to adoption suggests difficulties with the child and/or lack of family stability. This measure was negatively associated with IQ scores at time 1 and time 2, although the relationship was significant only at time 2. It may be that early family influences override early effects of multiple placements, but not later ones. However, the majority of adoptees had either none or only one pre-adoption arrangement, so additional research on this finding is warranted.

It is unclear why matched ethnicity was associated with a larger IQ difference at time 1. This relationship was not observed in the 2005 study, so may reflect some peculiarity of the small sample size. As in previous VT pair analyses, a history of attending the same class was associated with a smaller Verbal IQ difference, although the direction of causation is uncertain.

A caveat to the present study is the reduced sample size that precluded some meaningful analyses. Developmental comparisons between adoptees in adoptive–adoptive and adoptive–biological VT pairs would have tested the hypothesis of greater IQ gain among the latter. Availability of the complete WISC-III would have allowed analyses of developmental changes in the mental ability profile. However, the Fullerton Virtual Twin Study is ongoing and additional intellectual assessments are planned. These data will be complemented by IQ data from a new prospective study of young Chinese twins separated at birth and reared by different families (Segal, in press).

In summary, the present study showed decreasing shared environmental influence on intellectual development in early and middle childhood, given the decreased resemblance of virtual twins at follow-up. This effect is consistent with increased contributions from genetic and/or non-shared environmental factors to mental development. Increased focus on the educational environments of adopted children may provide clues as to the best ways to support the development and expression of their abilities. New ways of using VTs in behavioral-genetic research may help to address developmental questions of interest to researchers studying children and the families who raise them.

Acknowledgments

The contributions of the families and research assistants are gratefully acknowledged. This work was supported, in part, by a National Science Foundation award (SBR-9712875), a stipend for Research, Scholarship and Creative Activity from California State University, Fullerton, and an NIMH Grant (R01 MH63351).

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Table 1

Age (in years) and age difference of virtual twins (in months) at time 1 and time 2 (*N* = 43 pairs)

Measure	Time	Mean	SD	Range
Age at testing (84)	1	5.11	1.10	4.00–8.70
	2	10.77	1.61	7.18–13.67
Age difference at 1 testing [43]	1	3.05	2.62	0.00–8.93
	2	3.02	2.64	0.00–8.93

(*N*) = individuals; one adoptee paired with triplets was counted only once in individual analyses.

[*N*] = pairs or families.

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Table 2

Virtual twins IQ scores at time 1 and time 2

Time	Mean[a]	(SD)	Range	$r(T1, T2)$
Full IQ score[b]				
1	105.86	(11.41)	83–135	
2	108.89	(13.25)	81–145	
$T1–T2$	3.03	(12.38)	−28–31	.50**
2005 Sample	105.87	(13.61)	70–148	
Verbal IQ score[c]				
1	105.27	(12.28)	74–129	
2	109.64	(12.62)	75–141	
$T1–T2$	4.37	(11.90)	−38–30	.54**
2005 Sample	105.17	(14.33)	62–150	
Performance IQ score				
1	105.48	(12.29)	73–135	
2	106.87	(18.17)	68–146	
$T1–T2$	1.39	(17.18)	−39–42	.42**
2005 Sample	105.60	(13.58)	70–144	

[a] Individual data ($N = 84$; $N = 221$, 2005).

[b] $t(83) = -2.25$, $p < .05$.

[c] $t(83) = -3.36$, $p < .001$.

** $p < .01$.

Table 3

Virtual twins IQ intraclass correlations, within-pair differences, and 95% confidence intervals at time 1 and time 2 (N = 43 pairs)

Time	r_i	95% CI	Within-pair diff[a]	(SD)	Range
Full IQ[a]					
1	.30*	(.01, .55)	10.74	(8.31)	0–40
2	.11	(−.19, .39)	14.12	(10.39)	0–50
2005[d]	.26**	(.08, .42)	13.22	(9.99)	0–45
Verbal IQ[b]					
1	.24	(−.06, .50)	11.74	(9.55)	0–41
2	.17	(−.13, .44)	12.79	(10.01)	0–35
2005[d]	.23**	(.05, .40)	13.71	(11.13)	0–53
Performance IQ[c]					
1	.27*	(−.03, .52)	12.05	(8.64)	0–36
2	.06	(−.24, .35)	19.93	(14.58)	0–62
2005[d]	.21**	(.03, .38)	14.00	(9.73)	0–37

[a] 1 vs 2: [$t(42) = -2.03$, $p < .05$].

[b] 1 vs 2005: [$t(154) = -12.40$, $p < .001$; 21 vs 2005; $t(154) = 9.85$, $p < .001$].

[c] 1 vs 2: [$t(42) = -3.41$, $p < .001$]; 1 vs 2005; $t(154) = 9.75$, $p < .001$].

[d] N = 113 pairs.

* $p < .05$.

** $p < .01$.

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Table 4

IQ scores for biological and adoptive siblings, and correlations with rearing status, at time1 and time 2

	Biological sibs *n* = 13		**Adoptive sibs *n* = 71**		**Rearing status adop, biol**
	Mean	**(SD)**	**Mean**	**(SD)**	***r*(*n* = 84)**
IQ[a]	107.00	(11.45)	105.65	(11.47)	.04
IQ2	116.85	(18.98)	107.44	(11.51)	.26*
IQ–IQ2[d]	−9.85	(16.58)	−1.79	(11.16)	.26*
VIQ[b]	105.77	(12.76)	105.18	(12.28)	.02
VIQ2	112.92	(18.38)	109.04	(11.34)	.11
VIQ–VIQ2[e]	−7.15	(17.35)	−3.90	(10.71)	.26*
PIQ[c]	106.77	(11.90)	105.24	(12.42)	.05
PIQ2	118.23	(20.45)	104.79	(17.07)	.27*
PIQ–PIQ2[f]	−11.46	(16.79)	0.45	(16.72)	.26*

[a] IQ2: $t(82) = -2.42$, $p < .05$; $F = 2.72$, $p < .01$.

[b] VIQ2: $F = 2.63$, $p < .01$.

[c] PIQ2: $t(82) = -2.23$, $p < .05$.

[d] IQ–IQ2: $F = 2.21$, $p < .05$.

[e] VIQ–VIQ2: $F = 2.63$, $p < .01$.

[f] PIQ–PIQ2: $t(82) = 2.36$, $p < .05$.

* $p < .05$.

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Table 5a

Correlations between IQ, verbal IQ and performance IQ scores and individual characteristics at time 1 and time 2

Individual data	**IQ** **IQ2**	**VIQ** **VIQ2**	**PIQ** **PIQ2**
Age at testing (84)	.20 −.10	.14 −.05	.23* −.09
Pair type (84)	.05 .23*	−.02 .14	.12 .21
Age entered family (84)[a]	−.28** −.21	−.28* −.33*	−.18 −.04
Age at adoption (71)	−.29* −.19	−.29* −.36**	−.19 .02
Birth order (84)	−.03 −.04	−.09 −.12	.07 .04
Sex (84)	.13 .04	.08 −.08	.13 .11
Ethnicity/race (84)	.02 −.07	−.00 −.11	.06 −.01
No. of living situations (72)	−.18 −.26*	−.11 −.22	−.18 −.17

n's: individuals.

[a] Age at adoption for adoptive siblings; age at release from the hospital for biological siblings.

* $p < .05$.

** $p < .01$.

Table 5b

Correlations between IQ, VIQ and PIQ difference scores and pair characteristics at time 1 and time 2

Pair data (*N* = 43)	**IQ diff IQ diff 2**	**Verbal IQ diff Verbal IQ diff 2**	**Perf IQ diff Perf IQ diff 2**
Mean pair age (days)	−.02 −.04	−.05 −.13	−.02 −.10
Age diff (days)	−.02 .09	.12 .05	.04 −.06
Diff. in age at testing (days)	.00 .09	.13 .05	.05 .06
Sex of pair (same/opp)	−.12 −.28	−.20 −.07	−.28 −.11
Pair type (AdAd/AdBi)	−.02 .36*	.06 .17	.24 .25
Ethnicity/race (same/diff)	−.31* −.24	−.01 .00	−.47** −.06
Class (same/diff) (*n* = 40,43)	.15 −.30*	.25* −.19	.20 −.04
% Yrs same class (*n* = 13) Kind >>	−.08 —	−.17 —	−.10 —
% Yrs same class (*n* = 41) PreSch >>	−.19 —	−.33* —	−.12 —

* $p < .05$.

** $p < .01$.