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## Article

# The Louisville Twin Study: Past, Present and Future

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### Abstract

The Louisville Twin Study (LTS) is nationally recognized as one of the largest and most comprehensive studies of child development related to multiple birth status. The LTS is unique because of the extensive longitudinal face-to-face assessments, the frequency of data collection, the inclusion of data on additional family members (i.e., parents, siblings, grandparents; and later, twins' own spouses and children), and the variety of data collection methods used. Data preservation efforts began in 2008 and are largely complete, although efforts are ongoing to obtain funding to convert the electronic data to a newer format. A pilot study was completed in the summer of 2018 to bring the twins, who are now middle-aged, back for testing. A grant is currently under review to extend the pilot study to include all former participants who are now ≥40 years of age. Opportunities for collaboration are welcome.

**Keywords:** twin study; behavior genetics; longitudinal study

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### History

The Louisville Twin Study (LTS) was started in 1957 by Dr Frank Falkner, who was a pediatrician and Chair of the Department of Pediatrics at the University of Louisville School of Medicine. Dr Faulkner was a pioneer in the use of twin study methodologies to study physical growth in infants and children. Dr Steven Vandenberg joined Dr Faulkner in 1960 and expanded the focus to include measures of cognition, personality, physical development and environmental factors over time (Rhea, 2015; Vandenberg et al., 1968). On Dr Vandenberg's departure in 1967, Dr Ronald Wilson took over the directorship and continued to grow the study with a focus on developmental synchronies of cognitive development. Dr Adam Matheny served as the Associate Director from 1969 to 1986 when he became the Director upon the sudden passing of Dr Wilson. Although Dr Matheny collaborated with Dr Wilson on the cognitive development work (Wilson & Matheny, 1983), he is best known for his research related to temperament, behavior and personality (Matheny, 1986, 1987, 1989). Dr Kay Phillips joined the LTS in 1988 and became the Acting Director in 2000 when Dr Matheny retired. Dr Phillips ushered in the use of contemporary genomic methods (Rhea, 2015). Due to difficulties with securing funding, the LTS began closing in 1999. Data collection continued until the final closure in 2000 and has been on indefinite hiatus. In 2008, Dr Deborah Winders Davis was appointed as Director of the LTS. Recent activity in the LTS under her directorship is described in a later section.

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In addition to the longitudinal twin study, Dr Marilyn Riese had a 30 years' research career at the LTS examining infant behavioral development (Riese, 1986, 1987, 1988, 1990, 1995, 1998, 2001; Riese et al., 1985). Other smaller cross-sectional studies of twins were also conducted. Only the longitudinal twin study data will be discussed in this article.

### Significance

The LTS was nationally recognized as one of the largest and most comprehensive studies of child development related to multiple birth status (Falkner, 1956; Matheny et al., 1984; Vandenberg et al., 1968; Wilson, 1972, 1978, 1983, 1986; Wilson et al., 1971; Wilson & Matheny, 1986). At the height of study activity, it was considered to be a 'premier study in the field of human developmental behavioral genetics' (Fulker et al., 1988, p. 10). The LTS is unique because of the extensive longitudinal assessments and because of the relatively low rate of mobility out of the area. Face-to-face data collection, the frequency of data collection, the inclusion of data on additional family members (i.e., parents, siblings, grandparents; and later, twins' own spouses and children), and the combination of parent report, researcher observation and standardized testing make the data set an invaluable resource.

The LTS was continuously funded for more than 40 years before it was closed down between 1999 and 2003. Scientific analysis of the Louisville sample dwindled rapidly during the 1990s, with almost 90% of total publications based on the study appearing before that time. Nevertheless, the study produced several hundred publications, many of them consensus classics (Matheny, 1989; Matheny et al., 1981, 1984; Wilson, 1983, 1986), but the LTS data have not been exhausted in terms of the contribution they could make to current developmental behavioral genetics (see Appendix A: Publications from the Data).

**Table 1.** Number of participants for each testing wave

| Visit | Number of individuals | Number of twin pairs |
|---|---|---|
| At birth | 1770 | 885 |
| 3 months | 922 | 457 |
| 6 months | 1147 | 571 |
| 9 months | 1130 | 563 |
| 12 months | 1366 | 681 |
| 18 months | 1276 | 631 |
| 24 months | 1269 | 584 |
| 30 months | 866 | 431 |
| 36 months | 1177 | 566 |
| 4 years | 1047 | 520 |
| 5 years | 973 | 486 |
| 6 years | 912 | 456 |
| 7 years | 771 | 384 |
| 8 years | 779 | 389 |
| 9 years | 708 | 354 |
| 12 years* | 184 | 92 |
| 15 years | 558 | 278 |

*Assessments at the age of 12 years were added later resulting in a smaller data set for that age relative to the other assessment points.

In 2014, a group of multidisciplinary researchers that included the current authors was awarded a grant (1R03AG048850-01) to undertake recovery of the existing LTS data set. As the LTS was closing, data continued to be collected, but it was never entered into any type of electronic format. Since receiving the R03, we have built on the existing data sets, increasing available sample sizes at crucial ages by more than 20%, supporting five presentations and four publications (Beam et al., 2015; Davis et al., 2015; Finkel et al., 2015; Turkheimer et al., 2015), collected in a special section of the journal *Behavior Genetics* honoring the career of Adam Matheny.

## Data

### *Sample*

The LTS sample is a randomly selected sample of families who represented the full range of socioeconomic status (SES) and racial/ethnic diversity within the metropolitan area (Louisville, Kentucky, USA) at the time of recruitment. Approximately 80% of the participants are European-American, 18% are African-American and the remaining 2% are of mixed or Asian ancestry. Occupations of heads of households, converted to Duncan's scores for SES, represented the entire distribution of social class, with the average score on the 100-point scale equal to 46.9 ($SD = 26.9$; score range typical for middle-level clerical workers). Special efforts were made to retain families that were recruited into the study. Less than 10% of the sample withdrew from the longitudinal study during the first 3 years. The sample includes 24% male monozygotic (MZ) pairs, 19% female MZ pairs, 17% male dizygotic (DZ) pairs, 18% female DZ pairs and 22% opposite-sex DZ pairs. The sample is 51% female. Blood typing was used to assign zygosity.

Data collection was also done on a small sample ($n = 147$) of children of twins (COT). In that sample, the same measures were collected as were collected for the twins in the larger study.

### *Data Collection*

Data were collected at birth; 3, 6, 9, 12, 18, 24, 30 and 36 months; and 4, 5, 6, 7, 8, 9 and 15 years (see Table 1 for sample size per testing waves). Assessments at the age of 12 years were added later resulting in a smaller data set for that age relative to the other assessment points (see Table 1). In addition to data collection on twins and other multiples, data were collected at the same ages for nontwin siblings. Parent measures were generally collected only once. A comprehensive set of measures examined cognitive ability, physical growth, parent-reported temperament, behavioral observations and environmental characteristics (see Table 2 and Appendices A and B).

In addition to surveys, observations and cognitive testing, the LTS data also include repeated video recordings of the twins participating in interactions analogous to the Strange Situation assessment of infant–caregiver attachment (Finkel & Matheny, 2000). The original videos began with reel-to-reel tape and later switched to video cassette tapes recordings. All reel-to-reel recordings have been transferred to video cassette tapes. A large portion of the video cassette tapes have been converted to a digital format.

### *Data Formats*

Data were originally collected predominantly on paper. As technology became available, data were entered and stored in ASCII text files using a card punch system, which was the standard at the time. This method resulted in more than 1100 ASCII text files being generated such that 1 ASCII text file would contain all Bayley Scales of Infant Development assessments done at the age of 6 months. Another ASCII text file would include the same tests done at 9 months and so on. As new data have been entered, Excel files have been created. All paper files have been scanned along with all documentation (see below in Recent Activity).

## Recent Activity

Efforts, supported by the University of Louisville, began in late 2008 to catalog and recover the longitudinal data, which existed on paper, ASCII text and VHS video files. The original data dictionaries and other documentation were meticulously maintained and are available. Paper data and other documents were scanned to guard against loss of data from aging paper and natural disasters. Many video files were converted to digital files, but work remains to complete the video transfers.

The R03 grant from the National Institute of Aging facilitated data-recovery efforts and allowed for secondary data analyses to be conducted from the existing data. Remaining data collected on paper, but never entered into electronic files, were archived electronically. Thus, all data from the childhood period of the LTS have been entered, checked, validated and cleaned, as appropriate.

In 2016, two separate pilot studies were conducted using different methods for locating former LTS participants. For each pilot, 100 (Method 1) and 103 (Method 2) different families were randomly drawn from the LTS database. Because of the different methods used, success rates differed significantly: 86% (Method 1) versus 95% (Method 2), chi-square = 5.0, $p < .05$. These efforts allowed us to demonstrate two salient points: (1) we can relocate the twins even after up to 54 years since the last time they participated and (2) the families we can find differ only modestly from the families we had difficulty finding. First, a total of 184 (or 91%) of the 203 families in both pilot studies were identified using publicly available data, allowing us to estimate conservatively that we can find 845 of the


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**Table 2.** Summary of general variable categories and ages at assessment

| Variable | Subject | Age |
|---|---|---|
| Cognitive ability | Children (Multiples/ Siblings) | Birth, 6, 9, 12, 18, 24, 30 months; 3, 4, 5, 6, 7, 8, 9, 12, 15 years |
| | | One adult measure (>18 years) |
| | Parents | One adult measure |
| Physical | Children | Birth, 6, 9, 12, 18, 24, 30 months; 3, 4, 5, 6, 7, 8, 9, 12, 15 years |
| Measurements | | One adult set of measurements (>18 yrs) |
| | Parents | One set of measurements |
| Temperamentquestionnaires | Children (by parents) | Birth, 6, 9, 12, 18, 24, 30 months; 3, 4, 5, 6, 7, 8, 9, 12, 15 years |
| | Children (by 1st grade. teacher) | 6 or 7 years |
| | Children (self) | 12, 15 years |
| | | One adult set of measures (18+ years) |
| | Parents (self) | One measure; variable time |
| Behavioral | Children (during play) | 6, 9, 12, 18, 24, 30 months; 3, 4 years |
| assessments | Children (during testing) | 6, 9, 12, 18, 24, 30 months; 3, 4, 5, 6, 7, 8, 9, 12, 15 years |
| | Children (physical measurements) | 6, 9, 12, 18, 24, 30 months; 3, 4, 5, 6, 7, 8 years |
| | Neonatal assessments | Birth |
| Home | Home visits | 7 months; 3, 6 years |
| environment | Family Environment Scale (FES) | 12, 15 years (children) |
| | | 6 months; 3, 6, 9, 12, 15 years (parent report) |
| | SES/ED — Parents | One adult measure (>18 years) |
| | Children | Birth, 7 months; 3, 6, 9, 15 years |
| | CAR (Chaos in Auto Rating) | 6, 9, 12, 18, 24, 30 months; 3, 4, 5, 6, 7, 8, 9, 12, 15 years |

Note: The LTS consists of one cohort for which these data were collected. Cognitive and physical measures were collected from the inception. Temperament, behavior and environmental measures began in the 1970s.

original sample of 929 families. Second, we conducted logistic regressions to predict which families can be found from relevant demographic variables. Using Method 2, which was the most robust, SES, race and sex were not predictive of the outcome. Children from families found in the pilot participated in significantly more waves of testing ($M = 9.67$; $SD = 5.2$) than those who were not found ($M = 6.05$, $SD = 5.9$). These pilots suggest that finding these families for future studies is probable and enhances the usefulness of the childhood data, as data collection on twins extends into midlife to investigate cognitive, psychosocial and environmental risk factors related to cognitive aging and impairment.

Our ability to recruit twins to participate in a new phase of study was demonstrated in our 2018 Midlife Pilot Study. Between July 30, 2018 and August 10, 2018, we coordinated an in-person pilot study, once again based in the Department of Pediatrics at the University of Louisville School of Medicine, to collect cognitive, memory and biomarker data from 40 individual twins aged 40–64 years. The response was overwhelming, with over 100 twins responding to a Facebook advertisement. Within 2 weeks, 42 twins were scheduled and 40 participated, making the LTS the longest longitudinal twin study in the USA. (We note that the two twins who canceled did so because of logistical reasons and not because they were opting out of future data collections.) For the pilot study, twins returned to Louisville from as far away as San Diego, Washington DC, Indianapolis and Nashville, supporting the possibility of in-person interviews with nearly all twins as was done during their early life interviews. All twins consented to the blood draws. Each twin was administered a Wechsler Adult Intelligence Scale-IV battery, a California Verbal Learning Test-II, blood draws, functional ability measures (lung function test, gait speed and grip strength), the Symptom Checklist 90 to measure psychiatric health and the SF-36 to measure physical health. Blood was used to extract a set of biomarkers for the estimation of Levine's biological age. The LTS response rate is consistent with participation rates during childhood and adolescence. The 2018 pilot demonstrates that LTS twins are eager to participate in the proposed study; study personnel are prepared for all facets of data collection; LTS participants are diverse in their cognitive and physical states of health; and we have established protocols for storing and analyzing biologic samples.

## Future Directions

An R01 is currently under review to extend the above pilot study for all former participants to conduct in-person cognitive functioning and physical assessments and collect blood from each twin to quantify biological age and plasma beta-amyloid (Aβ) and to genotype them. Our aims are to specify the causal effects of accelerated age on midlife accumulation of Aβ, a central risk factor of Alzheimer's disease, and cognitive functioning at midlife; and to specify causal effects of early life developmental mechanisms on biological age, Aβ accumulation and cognitive functioning at midlife. If funded, the LTS will be a true lifespan development twin study.

Efforts will continue to seek funding to convert the electronic data into a relational database for easier use. Policies and procedures will be developed to facilitate data sharing with outside investigators. Efforts will continue to seek funding for data collection in adulthood.

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## Appendix A. Publications from the data

### Studies Prior to 2004

These data contributed to approximately 200 publications from 1958 to 2003. Selected examples are presented below by decade.

**1960**[2–8]

2. Vandenberg, S. G. (1964). Hereditary factors in physical growth: A study of identical and fraternal twins examined repeatedly. American Journal of Physical Anthropology, 22, 501.

3. Vandenberg, S. G, & Kelly, L. (1964). Hereditary components in vocational preferences. Acta Geneticae Medicae et Gemellologiae, 13, 266–277.

4. Vandenberg, S. G., & Strandskov, H. H. (1964). A comparison of identical and fraternal twins on some anthropometric measures. Human Biology, 36, 45–52.

5. Vandenberg, S. G. (1965). Multivariate analysis of twin differences. In S. G. Vandenberg (Ed.), Research methods and goals in human behavior genetics (pp. 29–43). New York: Academic Press.

6. Brown, A. M., Stafford, R. E., & Vandenburg, S. G. (1967). Twins: Behavioral differences. Child Development, 38, 1055–1064.

7. Vandenberg, S. G. (1968). Primary mental abilities or general intelligence? Evidence from twin studies. In J. M. Thoday & A. S. Parkes (Eds.), Genetic and environmental influences on behavior (pp. 146–160). Edinburgh: Oliver and Boyd.

8. Andrews, B. F., & Falkner, F. (1968). Fetal hemoglobin synthesis in fraternal and identical twins. Biologia Neonatorum, 12, 23–28.

**1970**[9–21]

9. Wilson, R. S. (1970). Bloodtyping and twin zygosity. Human Heredity, 20, 30–56.

10. Matheny, A. P., Jr. (1971). Genetic determinates of the Ponzo illusion. Psychonomic Science, 24, 155–156.

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12. Wilson, R. S. (1972). Twins: Early mental development. Science, 175, 915–917.

13. Wilson, R. S., & Harpring, E. B. (1972). Mental and motor development in infant twins. Developmental Psychology, 7, 277–287.

14. Matheny, A. P., Jr., & Brown A. (1974). A twin study of genetic influences in reading achievement Journal of Learning Disabilities, 7, 99–102.

15. Matheny, A. P., Jr., & Dolan, A. (1975). Sex and genetic differences in hair color during childhood. American Journal of Physical Anthropology, 42, 53–56.

16. Wilson, R. S. (1975). Twins: Patterns of cognitive development as measured on the Wechsler Preschool and Primary Scale of Intelligence. Developmental Psychology, 11, 126–134.

17. Dolan, A. B., & Matheny, A. P., Jr. (1976). Separation from attachment figures: Responses of young children in a supportive setting. JSAS Catalog of Selected Documents in Psychology, 6, 16.

18. Matheny, A. P., Jr., Dolan, A. B., & Wilson, R. S. (1976). Twins: Within-pair similarities on Bayley's Infant Behavior Record. Journal of Genetic Psychology, 128, 263–270.

19. Wilson, R. S., & Matheny, A. P., Jr. (1976). Retardation and twin concordance in infant mental development: A reassessment. Behavior Genetics, 6, 353–358.

20. Wilson, R S. (1977). Twins and siblings: Concordance for school-age mental development. Child Development, 48, 211–216.


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21. Wilson, R. S. (1979). Twin growth: Initial deficit, recovery, and trends in concordance from birth to nine years. Annals of Human Biology, 6, 205–220.

**1980**[22–31]

22. Matheny, A. P., Jr. (1980). Visual-perceptual exploration and accident liability in children. Journal of Pediatric Psychology, 5, 343–351.

23. Matheny, A. P., & Dolan, A. B. (1980). A twin study of personality and temperament during middle childhood. Journal of Research in Personality, 14, 224–234.

24. Riese, M. L. (1980). Assessment of gestational age in twins: Lack of agreement among procedures. Journal of Pediatric Psychology, 5, 9–16.

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32. Riese, M. L. (1990). Neonatal temperament in monozygotic and dizygotic twin pairs. Child Development, 61, 1230–1237.

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**2000**[39–43]

39. Finkel, D., & Matheny, A. P., Jr. (2000). Genetic and environmental influences on a measure of infant attachment. Twin Research, 3, 242–250.

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**Studies from recent R03 (1R03AG048850–01)**

**2015**[43–46]

43. Beam, C. R., Turkheimer, E., Dickens, W. T., Davis, D. W. (2015). Twin differentiation of cognitive ability through phenotype to environment transmission: The Louisville Twin Study. Behavior Genetics, 45, 622–634.

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## Appendix B. Summary of study measures for twins, other multiples, non-twin siblings, and children of twins (COT)

**Demographics**

Blood type

Family configuration (biological parents, stepparents, siblings, etc.)

Parent education

Parent occupation

Race

Socioeconomic status (Hollingshead)

Zygosity

**Cognitive**

Bayley Scales of Infant Development (versions 1 and 2)

Wechsler Preschool & Primary Scale of Intelligence (WPPSI and WPPSI-R)

Stanford Binet

McCarthy Scales of Children's Abilities

Wechsler Intelligence Scale for Children (WISC, WISC-R and WISC-III)

**Behavior**

Early Infancy Temperament Questionnaire (EITQ)

Cattell Personality Questionnaire (CPQ)

Infant Behavior Record (IBR; Bayley)

Behavior Rating Scale (BRS; Bayley, 2nd edition)

Infant Behavior Questionnaire (IBQ)

Middle Childhood Temperament Questionnaire (MCTQ)

Behavior Rating Scale School-age (BRSS)

Infant Temperament Questionnaire (ITQ)

McDevitt Style Questionnaire (MSQ)


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Thurstone Temperament Scale (mother and father)
Dimensions of Temperament Survey — Revised (DOTS-R)
School Behavior Checklist (SBC)
Louisville Behavior Checklist (LBC)
Assertive–Submissive–Aggressive (ASA; Robin Young Questionnaire)
Minnesota Multiphasic Personality Inventory Adolescent (MMPI-A)
Temperament Ratings 3–30 months (observation)
Temperament Ratings 36–48 months (observation)
Behavior during physical measurements (observation)
Injury Summary
Injury Behavior Checklist (IBC)
Health Accident Locus of Control (HAL)

**Environment**

Parent Interview (3–30 months)
Parent Interview (36–72 months)
Parent Interview (12 and 15 years)
Home Interview (family routines, parent–child interactions, parenting style, home environment, nutrition)
Confusion, Hubbub and Order Scale (CHAOS)
CHAOS in Auto Rating (CAR)
Family Routines Inventory
Family Environment Scale (Moos)

**Physical Measures**

Birth weight
Weight
Lying height (3–24 months)
Crown-to-rump length (3–24 months)
Standing height (>30 months)
Sitting height (>30 months)
Head circumference
Arm circumference
Calf circumference
Humerus length
Femur length
Hair color
Eye color

**Measures for Parents**

Weight
Height
Head circumference
Eye color
WAIS-R/WAIS-III
Perceived Stress Questionnaire
Locus of Control


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