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Twins: The finest natural experiment

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ABSTRACT

Twin studies have moved beyond the classic design described by Galton (1875). Natural experiments involving twins and twin-like individuals occur constantly, driven largely by artificial reproductive technology and increased adoption rates. These events have produced exotic twin and sibling relations, e.g., virtual twins (same-age unrelated siblings) and twins reared apart (Chinese twin girls, abandoned and adopted separately). Research designs utilizing the unique genetic and social relatedness of such individuals can inform numerous behavioral domains. Many studies to be described were inspired by my association with the Minnesota Study of Twins Reared Apart (1982–1991), directed by Bouchard.

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1. Introduction

Twin studies have moved far beyond the classic design (Galton, 1875). One of the most informative approaches involves studying monozygotic (MZA) and dizygotic (DZA) twins reared apart and reunited. Correlations between MZA co-twins provide pure estimates of genetic influence on developmental traits. Correlations between DZA co-twins enable informative comparisons with MZA twins. Greater resemblance between MZA than DZA twins is consistent with genetic influence on the trait(s) under investigation. This conclusion rests on the equal environments assumption, namely that relevant environmental influences do not differ between twin types (Plomin, DeFries, McClearn, & McGuffin, 2008).

Three studies conducted before 1965 and in three different countries (United States, England and Denmark) included 76 MZA sets (Juel-Nielsen, 1965; Newman, Freeman, & Holzinger, 1937; Shields, 1962). This situation changed following the 1979 reunion of 39-year-old MZA twin brothers from Ohio. These twins visited the University of Minnesota for psychological and medical assessment by Bouchard.

The Ohio twins showed striking similarities in intellectual development, occupational choices, medical characteristics and marital histories. This case led to the identification of 137 separated sets over the next 20 years; in some analyses triplets sets were counted as three pairs each. I worked with the twins between 1982 and 1991, an experience highlighting the unique insights twins can provide simply by acting naturally. It also encouraged appreciation for novel twinning situations that could bring new ideas to psychological research.

The present paper has two objectives. The first is to summarize findings from twin and adoption studies inspired by the Minnesota Study of Twins Reared Apart (MISTRA). The second is to construct a “gallery” of naturally occurring twin experiments that can sharpen understanding of selected traits. The paper concludes with a tribute to Bouchard who contributed so much to studies of twins reared apart.

2. Twin and adoption research: methods, findings and implications

2.1. Twins reared apart

2.1.1. Social relations

Reared apart twins offer superb tests of evolutionary-based hypotheses concerning the underpinnings of social relatedness. Hamilton (1964) proposed that natural selection favors alleles predisposing individuals to behave in ways that assist transmission of those alleles. Alleles prompting individuals to prefer others likely to carry copies of those alleles would be an indirect way to transmit one's genes into subsequent generations. Expressions of altruistic behavior should, therefore, vary in accordance with interactants' genetic relatedness. Evolutionary reasoning generates the expectation that MZ twins will show closer social relations than DZ twins. This finding, confirmed by numerous investigations (Segal, *in press*), is consistent with both evolutionary and psychodynamically-based explanations of twin group differences in social relations; social explanations emphasize the more similar treatment of MZ than DZ twins (Siemon, 1980).

A study of reared apart twins' social relatedness provides a more stringent test of factors affecting within-pair relationships than studies of reared together twins. This is because the twins

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grew up apart, often with no knowledge of one another. Fortunately, the early reared apart twin studies cited above appended biographical data to the quantitative findings. This material shows that 53% of the MZA twins developed close relationships, while only 18% did not; judgments were precluded for 29% of the pairs (Segal, Hershberger, & Arad, 2003). Unfortunately, DZA twins had not been recruited for these projects. The MISTRA included both MZA and DZA twin pairs, so offered an ideal opportunity to explore associations between genetic and social relatedness.

A Twin Relationship Survey (TRS) was created after I joined the MISTRA in 1982. The survey examined the twins' adoption, reunion and family relationships. Key questions concerned feelings of closeness and familiarity toward the co-twin. These questions were answered with reference to the meeting time (retrospective) and the participation time. They were repeated for adoptive siblings with whom the twins had been raised. The sample completing the TRS included 44 MZA twin pairs, 33 DZA twin pairs and seven individual twins and triplets.

MZA twins expressed greater within-pair closeness and familiarity than did DZA twins (Segal et al., 2003). Feelings of closeness exceeded feelings of familiarity, and current ratings exceeded initial ratings. Closeness and familiarity were greater for reared apart co-twins than for the adoptive siblings the twins had known all their lives.

This study was among the first to apply behavioral-genetic methodology to assess evolutionary-based hypotheses. The greater affiliation between MZA than DZA twins, and between twins than their adoptive siblings, is consistent with evolutionary theorizing. Contrary to some socially-based theories, shared time is not requisite to forming close relations; the six contact measures (e.g., age at reunion, contact time prior to assessment) correlated only slightly with the social relatedness measures. Associations between social relatedness and similarity in self-ratings of personality, interests, values and education yielded few significant findings. Twins' perceptions of their behavioral similarities may be more important mediators of their social relatedness than similarity in their self-report measures of personality and interests.

2.1.2. Age at menarche

Age at menarche (AAM) is a significant developmental event in the lives of young women. Studies of reared together twins have shown greater MZ than DZ twin resemblance in AAM, consistent with genetic influence (Kaprio et al., 1995). Correlations range between .65 and .97 for MZ twins, and between .18 and .50 for DZ twins. Intra-pair differences range between 0.08 and 1.25 years for MZ twins and between 0.56 and 1.35 years for DZ twins.

Findings on reared apart twins' AAM have been scant. Farber (1981), in a summary of the older literature, reported a within-pair difference of 9.30 months for MZA twin pairs. Shields' (1962) study of separated British twins indicated an interval of 6 months or less for MZA twin pairs ($n = 9$), but as much as 18 months to 4 years for some. These findings, in combination with the reared together twin data, additionally suggest effects from shared environmental influences.

Segal and Stohs (2007) conducted the first formal study of AAM in female twins reared apart. Participants included 27 MZA twin pairs and 21 DZA twin pairs from the MISTRA. A comparison group of 33 MZ twin pairs and 14 DZ reared together twins (MZT and DZT) was assembled from other University of Minnesota studies. Intraclass correlations for AAM were .56 and .16 for the MZA and DZA twins, respectively, and .70 and .41 for the MZT and DZT twins, respectively. These twin group differences are consistent with those provided by the early twin studies, i.e., genetic influence on AAM is indicated by greater MZA than DZA resemblance, and a shared environmental component is suggested by greater

resemblance between twins reared together than twins reared apart.

Some evolutionary theorists have linked earlier menarche to reduced paternal investment in daughters (Belsky, Steinberg, & Draper, 1991; Ellis, 2004). This study, using data from the Twin Relationship Survey described above, found that greater paternal understanding was significantly associated with earlier age at menarche, with a comparable trend found for maternal understanding. This finding does not support evolutionary predictions. It was suggested that resource availability may have mediated the relationship between paternal investment and AAM. In other words, adoptive families make special efforts to acquire children and also tend to be financially secure. It may be that parental provision of ample nutrition, health care and psychological investment contributed to earlier AAM in adoptive daughters.

2.1.3. Age at first intercourse

Twin studies have provided evidence of genetic influence on age at first intercourse (AFI). Heritabilities range between .00 and .72 for males and .15 and .49 for females. Heritability of AFI is also generally higher among younger than older twin cohorts (see Segal & Stohs, 2009). Until recently, a study of AFI using twins reared apart had never been conducted.

Segal and Stohs (2009) compared AFI in 34 MZA twin pairs, 25 DZA twin pairs and 23 individual twins from the MISTRA. Genetic influence on AAM was indicated by higher MZA ($r_1 = .34$) than DZA ($r_1 = -.22$) intraclass correlations. The MZA intraclass correlation (equivalent to an estimate of heritability) is consistent with findings from twins reared together. It is, however, somewhat problematic to explain the negative DZA correlation. Such a finding in reared together DZ twins could reflect sibling interaction effects, but that cannot be relevant here.

Relationships between AFI and selected life history events were examined among the female twins. Ages at first kiss, marriage and childbirth, as well as the menarche–intercourse interval, were significantly associated with AFI. Specifically, younger ages and a shorter interval were associated with earlier AFI. Twins engaging in earlier intercourse felt less happy than their peers and less fulfilled at home than those engaging in later intercourse; however, AAM and most rearing family variables showed no association with AFI. A life history perspective may have more explanatory value for understanding associations among AAM and family dynamics, while a developmental perspective provides insights into adolescent sexuality by focusing on the role of peer relations and experiences.

2.1.4. Korean MZA female twins reared apart

Some critics of reared apart twin research have claimed that the prenatal and postnatal environments of separated twins were similar, minimizing genetic influence as an explanation of their adult similarities (Agin, 2007; Taylor, 1980). In fact, features of the shared prenatal environment often create differences between MZ co-twins (see Segal, 2000). Furthermore, most MISTRA publications have shown little contribution from the shared family environment (see Bouchard, Lykken, McGue, Segal, & Tellegen, 1990), yet this challenge continues. One approach to addressing this issue is studying MZA twins raised in different cultures. A unique MZA male twin pair, in which one co-twin was raised in Trinidad and the other in Nazi Germany, exemplify the finding that genetically identical individuals can be similar in behavior, despite fundamental family and cultural differences (Segal, 2007a).

The opportunity to study an 18-year-old MZA female twin pair in which one twin was raised in the United States and the other in South Korea occurred in 2008. The American twin and her mother were studied at California State University, Fullerton, while the Korean twin and her family were studied at Chonnam National

University by Dr. Yoon-Mi Hur, in Kwangju, South Korea (Segal & Hur, 2008). The twins had been separated on their day of birth and had met only one time prior to assessment, at age 16 years.

Outcome measures included life history characteristics (e.g., age at separation from the twin), physical and health-related traits (e.g., height, weight and age at menarche) and behavioral traits (e.g., IQ, personality traits and self-esteem). Zygosity was determined by examination of 13 short tandem repeat (STR) DNA markers.

The twins' heights were nearly identical, but their weight showed greater difference than expected for MZ twins (5.38 kg). The American twin had a larger BMI (25.30 vs. 23.10), a likely reflection of a higher fat diet. Both twins experienced menarche at a younger age (10.67 and 9.75 years) than is typical for Asian girls (12.67 years) (Hwang, Shin, Frongillo, & Shin, 2003), but only one twin (US) experienced menstrual irregularity. Both twins suffered from migraine headaches, although their symptom severity differed. The American twin participated in sports, while her Korean twin sister was "sedentary". Women's sports are not emphasized in Korea to the extent that they are in the United States. If the Korean twin had participated in sports it is possible that their BMI difference could have been greater.

The twins obtained identical WAIS-R IQ scores (107) and similar scores on two special ability tests. However, the American twin excelled in verbal IQ, while her sister excelled in non-verbal IQ. This difference could be partly linked to the high value placed on quantitative skills in South Korea. The twins' nearly matching high scores on the Rosenberg Test of Self-Esteem are noteworthy. This is because individuals from Asian cultures tend to show lower levels of self-esteem, a finding partly linked to greater acceptance of unfavorable appraisals of the self (Spencer-Rodgers, Peing, Wang, & Hou, 2004).

Genetic influence on self-esteem is suggested by this case study, consistent with some previous findings in the literature. Hur (2005) examined genetic and environmental contributions to self-concept in female preadolescent twins from South Korea and Minnesota, using the Piers-Harris Children's Self-Concept Scale. In both samples, shared and non-shared environmental influences best explained variation in popularity, anxiety, intellectual competence and school status. However, a model including additive genetic and non-shared environmental components showed a better fit to physical appearance and attributes, and behavior. The two samples differed significantly with reference to additive genetic and environmental factors underlying physical appearance and attributes, and intellectual competence and school status. For example, heritability was higher and non-shared environmental factors were lower for physical appearance and attributes among twins from South Korea, relative to twins from Minnesota. It was suggested that girls in South Korea may be more realistic in their self-appraisal of their appearance than girls in Minnesota. It is also worth noting that twins in the South Korean sample showed lower means scored than twins in the Minnesota sample on all self-esteem scales with the exception of popularity, consistent with findings by Spencer-Rodgers et al. (2004), cited above.

The Korean twin substantially outscored her American counterpart on both extraversion and neuroticism. The difference in extraversion may be partly linked to the majority status of the South Korean twin and the minority status of the American twin. (The American twin admitted to sensitivity over physical differences between herself and members of her community.) The twins' disparity in neuroticism could be linked to different cultural values and/or to the fact that the Korean twin was under stress from college entrance preparation.

The American twin played the violin, while her sister played the piano. They participated in duets during their single visit together.

2.1.5. Prospective study of twins reared apart: Chinese twin girls

A study of young Chinese twin girls reared apart (CTA), initiated at California State University, Fullerton (CSUF) in 2003, is closely aligned with the MISTRA (Segal, Chavarria, & Stohs, 2007). It is the first prospective study of reared apart twins. Data have been gathered for nine CTA pairs (4 MZ and 5 DZ), and 3-year follow-up visits are ongoing.

China's One-Child Policy (1979–present) and preference for males led to the abandonment of thousands of female infants (Evans, 2000). Among the abandoned Chinese children were twins adopted apart (CTAs) and together (CTTs). CTTs offer informative comparisons with the CTAs. Furthermore, transracial adoption of intact twin pairs has never been investigated. Other families have created virtual twins (VTs), a "twin-like" kinship composed of same-age unrelated children, many from China. These three rare sibships have never been studied together, yet they provide sensitive biological and environmental controls for one another. All three kinships are currently being studied at CSUF.

Twins complete the Wechsler IQ test and a twin relationship questionnaire. Parents complete documents covering their twin child's early life history, adoption adjustment, physical health, personality traits, activities, interests and education. Detailed records of reunion times are requested, as are descriptions of children's reactions to the first meeting with their twin. Parents also provide information about their education, occupation, income and home facilities, and teachers complete a standard report form.

CTAs ($n = 9$ pairs) have a mean age of 4.98 years ($SD = 1.67$), range: 3.19–7.82, and a mean age at separation of 72.75 days ($SD = 70$), range: 1.00–5.63. CTTs ($n = 30$) have a mean age of 6.77 years ($SD = 2.26$), range: 3.73–11.43. The IQ, personality, social relatedness and medical findings for both groups will be reported as sample sizes increase. A pair of separately raised twins meeting for the first time is shown in Fig. 1.

2.2. Virtual twins

Virtual twins (VTs) are same-age unrelated siblings raised together since infancy (Segal, 2007a). These unique pairs replicate twinship, but without the genetic link. VTs include two adopted children, or one biological child and one adoptee. These pairs directly complement MZA twins because they provide direct estimates of environmental influence on measured traits. The first VT pair was identified at the University of Minnesota in 1991. Additional pairs were studied more formally as part of the Fullerton Virtual Twin Study, yielding a current sample of 140 pairs. A list of strict criteria has been developed for defining virtual twins:

1. Common rearing before one year of age.
2. Age 4-years, or older, at the time of testing.
3. Maximum age difference of 9 months.
4. Enrolled in the same grade at time of testing.
5. Absence of birth difficulties.

The mean age of the current sample (140 pairs) is 7.79 years ($SD = 8.18$). Modest shared environmental effects on general intelligence in early childhood have been found (Segal, 1997, 2000; Segal & Hershberger, 2005). The VT IQ intraclass correlation has ranged from .17 (Segal, 1997; 21 pairs, age 9.36 years) to .28 (140 pairs, 7.79 years), so is generally stable. The correlations demonstrate that approximately 25% of individual differences in the general intelligence of young children are associated with shared environmental effects. This finding is consistent with results from twin studies (see Plomin et al., 2008).

An analysis of repeated IQ measures was completed for a subsample of 43 VT pairs who participated in TAPS (Twins, Adoptees, Peers and Siblings) (Segal, McGuire, Havlena, Gill, & Hershberger,



Fig. 1. MZA twins' first reunion, age 6 years. Photo Credit: Dr. Nancy L. Segal.

2007). TAPS is a multi-site collaborative investigation (McGuire, Segal, Whitlow, Gill, & Clausen, *in press*). The 43 VTs were tested at ages 5.11 years ($SD = 1.10$) and at 10.77 years ($SD = 1.61$). IQ intraclass correlations for this group were .30 and .11, respectively; within-pair IQ differences were 10.74 ($SD = 8.31$) and 14.12 ($SD = 10.39$), respectively. IQ differences between unrelated individuals chosen at random would be 17 points (Plomin & DeFries, 1980). The somewhat smaller within-pair VT difference may reflect the young age of the participants. The changes in these values reflect the increased effects of genes and/or non-shared environmental effects on general intelligence as children age. The influence of the shared family environment appears to be waning, consistent with longitudinal studies of ordinary adoptive siblings (Scarr, Weinberg, & Waldman, 1993).

Note that the .30 correlation is higher than the .17 correlation reported above for the first 21 pairs in the study. The 21 VT pairs had a higher mean age at testing than the 43 VT pairs, a fact that might explain their relatively lower IQ correlation.

A twin-virtual twin analysis of body mass index (BMI) demonstrated genetic and shared environmental effects (Segal & Allison, 2002). The variance was partitioned into non-additive genetic effects (61%), shared environmental effects (25.0%) and non-shared environmental effects (14%). These findings were replicated using 929 individuals from MZ, DZ and VT twin pairs (Segal, Feng, McGuire, Allison, & Miller, 2009): non-additive genetic effects (64%), shared environmental effects (26%) and non-shared environmental effects (10%); the additive genetic component was non-significant. Previous BMI studies have not detected shared environmental effects, possibly because they lacked the kinships used in these analyses.

VTs have also served as a comparison group for assessing genetic effects on tacit coordination (Segal, McGuire, Miller, & Havlena, 2008). Tacit coordination (TC) occurs when "two parties have iden-

tical interests and face the problem ... of coordinating their actions for their mutual benefit when communication is impossible" (Schelling, 1960, p. 54). It was expected that MZ twins would outperform DZ twins who would, in turn, outperform VT twins.

A sample including 53 MZ twin pairs, 85 DZ twin pairs and 42 VT twin pairs, 7–13 years of age, completed a TC task as part of TAPS. Each individual answered twenty questions, e.g., name a color and name a book. The twins answered these same questions again, but with the instructions to "end up with the same answers" as their twin.

Multivariate analyses showed that MZ twins scored highest in both the individual and coordination conditions. Scores in the coordination condition exceeded those in the individual condition. These findings can inform areas in evolutionary psychology concerned with mechanisms underlying associations between social closeness and genetic relatedness. Tacit coordination (and mutual awareness of non-negotiated matched choices) may represent a class of mechanisms by which relatives develop and maintain close social relations. That is, common independently made choices may function as unambiguous indicators of similarity.

3. Gallery of natural experiments

3.1. MZ twins switched-at-birth

Reared apart twins are separated mainly because of illegitimate birth, maternal death or financial hardship. However, there is a rare class of twins whose separation is unintentionally caused by "switching" of one twin with a non-twin by hospital staff. These events generate twins raised apart, "singleton twins" and alleged DZ twins.

Alleged DZ twins belong to the special class of non-biological siblings called *virtual twins*; see above. What distinguishes them from VTs is that they are raised believing that they are related, whereas VTs know that they are not. These pairs allow stringent tests of shared environments effects on behavior.

There have been six documented switched-at-birth MZ twin pairs. Three male infants were born on the same night in the same hospital in Fribourg, Switzerland – an MZ male twin pair and a single male infant. A nurse accidentally switched one twin and the single baby, creating an "unrelated DZ twin pair" and a "singleton twin". Thus, two children were raised by the wrong parents. The mistake was discovered when the children entered the same school at age six and the extraordinary physical resemblance of the true twins became apparent. Extensive medical assessments (blood tests and skin grafts) were completed to determine the relatedness of the supposed MZ pair (Franceschetti, Bamatter, & Klein, 1948; McIndoe & Franceschetti, 1949–50).

A similar switch involved three male infants who later participated in the MSTR (Segal, 2007a). Two other cases resulted when a Puerto Rican hospital switched one member of each of two MZ female twin pairs, creating two copies of the same unrelated set. The children were returned to their biological families at age two (Civil No. 88-764 HL, 1947). A fifth case was discovered in Poland in 2000 (Day, 2009), and a sixth case was discovered in the Canary Islands (Lopez, 2008); I will be reporting findings for this pair in the near future.

3.2. MZ twins discordant for measured traits

Some MZ co-twin differences occur naturally, offering information on the relevant prenatal and postnatal environmental factors involved. My first experience with this situation involved 8-year-old MZ female twins who participated in my doctoral research (Segal, 2000). One twin had had a marginally attached placenta,



Fig. 2. Handprints of MZ co-twins discordant for physical growth. Photo Credit: Dr. Nancy L. Segal.

depriving her of vital fetal nutrients. She was four inches shorter than her co-twin and had cardiac difficulties. The discrepancy in their hand size is shown in Fig. 2.

MZ twins discordant for gender identity offer unique insights into the origins of this behavior. Gender identity disorder (GID) involves difficulties surrounding identification with one's physical sex and the gender roles associated with that sex (American Psychiatric Association, 2000). Transsexualism (discordance between one's sexual anatomy and gender identity) occurs in only 1/30,000 males and 1/100,000 females (Michel, Mormont, & Legros, 2001).

There have been reports of transsexualism in four MZ female pairs, 0% concordant (Garden & Rothery, 1992; Green & Stoller, 1971; Segal, 2006), and in 26 MZ male pairs, 50% concordant (see Segal, 2006). In the female-to-male case (Segal, 2006) the transsexual twins' feelings of being born a male emerged too early (age 5-years or earlier) to be reliably linked to differential rearing. Trends revealed by data from the four case reports showed that higher birth weight and later age at menarche occurred in the transsexual co-twins, suggesting prenatal developmental differences. However, transsexualism is likely to be associated with multiple genetic, epigenetic, developmental and experiential influences.

3.3. "Mixed race" DZ twins

Some interracial couples have given birth to DZ twins who appear to come from different racial backgrounds (Segal, 2009). Researchers have speculated that such twins inherited different relevant genes from their parents. Such pairs have never been studied, but could yield information regarding life experiences in these age-matched siblings. "Caucasian-Hispanic" twins at my university experienced differential discrimination.

3.4. Look-alike unrelated pairs

A challenge to twin study findings is that MZ twins are alike because they look alike. However, as Rowe (1994) explained, "... matching people in physical appearance should have little effect on similarity in their psychological traits if these treatments lack causal influence on the biological functions relevant to broad traits" (p. 48). Several twin studies have shown this to be the case (e.g., Plomin, Willerman, & Loehlin, 1976). Sophisticated research designs may quell this criticism.

My laboratory recently launched a study of personality similarity in individuals who look alike, but are genetically unrelated. Participants include the look-alike pairs photographed by Canadian artist, Francois Brunelle. Individuals receive a background questionnaire, the Rosenberg Self-Esteem Inventory and the Personality Questionnaire (Rolland & De Fruyt, 2009). Look-alikes should show significantly less personality similarity than MZ and DZ twins.

3.5. Societal dilemmas

Two MZ twin situations have challenged judicial authorities responsible for managing them (Segal, 2009). The KaDeWe department store in Berlin was robbed in January 2009. Evidence identified three suspects, one of whom was an MZ male twin. Both twins denied having been at the crime scene, so convictions have not been possible. Epigenetic tests to identify the correct culprit are not available.

Some women have had sexual relations with both MZ male co-twins, resulting in pregnancy (Segal, 2007b). Assigning paternity and custody by legal authorities has proven impossible for the same reason that the KaDeWe case was derailed. In a strange twist of genetic logic, the children's grandmothers in these cases are known with 100% certainty.

4. Tribute to Tom

I worked for Tom Bouchard between 1982 and 1991, first as a post-doctoral fellow and then as a research associate and Assistant Director of the Minnesota Center for Twin and Adoption Research. One of my clearest memories is a photograph of strikingly beautiful elderly MZ female twins that followed Tom from office to office. It perfectly captured some essential elements of the aging process – the graying hair and matching creases showed that physical changes are largely influenced by genetic factors. Tom delighted in photographing reared apart twin participants next to this image. The photograph is reproduced in Fig. 3.

My 9-year association with the Minnesota Study of Twins Reared Apart was the most exciting and stimulating period of my academic career. I felt privileged to be part of this ground-breaking, world famous study. Tom also nurtured other twin research interests I had at that time (e.g., twin loss, twin Holocaust survivors), knowing how important it is for new Ph.Ds to have collegial support and guidance.



Fig. 3. MZ twins with similar physical aging patterns. Photo Credit: kathryn M. Abbe & France M. Gill.

My graduate school advisor, the late Dr. Daniel G. Freedman, encouraged me to study issues and topics that I loved. “Follow your bliss”, he would say. I am grateful to Tom Bouchard for letting me do just that.

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