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Design, Utility, and History of the Colorado Adoption Project: Examples Involving Adjustment Interactions¹

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Abstract

This paper describes the Colorado Adoption Project (CAP), a longitudinal study in behavioral development, and discusses how adoption studies may be used to assess genetic and environmental etiologies of individual differences for important developmental outcomes. Previous CAP research on adjustment outcomes in childhood and adolescence which found significant interactions, including gene-environment interactions, is reviewed. New research suggests mediating effects of menarche and religiosity on age at first sex in this predominantly middle-class, Caucasian sample.

Keywords

adoption studies; gene-environment interactions; adjustment

Adoption researchers often study the effects of adoptive placement on children's behavioral development. However, adoption can also be viewed as a naturally occurring social experiment which facilitates the separation of the effects of genetic background from rearing environment. Such an experiment is analogous to animal studies of cross-fostering, although it lacks the rigorous control animal experimenters are able to maintain over both the genetic background and rearing environments of their subjects—including the gestational environment of embryos and fetuses. From this perspective, adoption studies allow us to compare outcomes in children from intact nuclear families, who share both genes and family environment with their parents, with outcomes in adopted children, who share only rearing environment with their adoptive parents and genes plus prenatal environmental influences with their birth parents (Plomin, DeFries, McClearn, & McGuffin, 2008). These studies thus yield evidence about the relative importance of rearing environment, genetic background, and their potential interactions for behavioral development.

In some of the first large scale adoption studies from the previous mid-century, researchers studied both the process and the effects of placement in different environments. Skodak and Skeels (1945), for example, noted that adopted children's development was related to their

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birth parent characteristics but greatly enhanced by their rearing family's superior resources. The inspiration of studies such as these led to larger and more systematic adoption studies, one of which will be discussed in this paper.

Rather than follow the format of a strictly empirical paper with traditional sections for literature review, methods, results, and discussion, we provide an introduction to the utility of adoption studies as a vehicle for studying gene-environment interaction in general and to the Colorado Adoption Project (CAP) in particular, followed by empirical examples to illustrate this utility. With this in mind, this paper is organized in three parts. First we explain the rationale for utilizing adoption studies to study development and present some commonly used methods. We then describe in detail the design and some of the measures which have been used in the CAP, one of the most comprehensive developmental adoption studies to date, followed by findings from previously published CAP analyses of various aspects of adjustment measured during childhood and adolescence in this predominantly middle-class, Caucasian sample, emphasizing potential interaction effects. In the final section we provide a more traditional literature review, data collection, and analysis description for the adjustment measure, early sex initiation, and the interaction we have chosen to use as an illustrative example.

Research Assumptions

Two important considerations in the logic of the adoption design include 1) the degree to which adoptees and adoptive families are representative of the general population and 2) whether adoptees are selectively placed in adoptive families. An adoption study may yield biased results when the full ranges of rearing environments and genetic backgrounds are not present, or when a portion of these ranges are under- or over-represented, and outcomes are differentially influenced in these ranges (Stoolmiller, 2000). For example, due to the lengthy processes involved in almost all adoptions as well as the expense, the typical adoptive family may have a higher than average socio-economic status (SES) (Keyes, et al., 2008). On the other hand, birth parents who place their child for adoption may be influenced by very difficult personal economic circumstances (Leve, et al., 2007). For adopted children, neither genetic background (as inferred from the characteristics of the birth parents) nor rearing environment may be representative of the general population for income or SES.

Adoption placement practitioners may deliberately or inadvertently place children with families based upon shared salient characteristics. Similarly, potential adoptive parents may search for biological parents who fit a desired profile. In either case, when considering a behavioral outcome that is genetically influenced, selective placement leads to a correlation between the rearing environment and the genetic background of the child. This can inflate estimates of environmental influence, or over-estimate the importance of genetic factors for this behavior, if not controlled for statistically (Hardy-Brown, Plomin, Greenhalgh, & Jax; 1980).

Possible correlations between genes and environment are generally not recognized in most developmental research, and can lead to serious causal misattributions (Plomin, DeFries, McClearn, & McGuffin, 2008). Some developmental research causally attributes positive outcomes (e.g., reduced substance use or delayed sexual onset) to social environments (e.g., family dining habits, family cohesiveness, or degree of religious practice); however this conclusion would be incomplete or misleading if there is a gene-environment correlation which partially or fully explains the relationship between these outcomes and the social environment. For example, the religious environment in the home may be viewed as a causal environmental factor for adolescent sexual onset, but it is also possible that parents' religiosity is partially heritable and contributes to both the environmental and genetic

influences on an adolescent's decision to delay sexual onset (D'Onofrio, B.M., Eaves, L.J., Murelle, L., & Maes, H.H., 1999).

When behaviors are influenced by correlated genetic and environmental causes, it becomes problematic to estimate the relative contributions of genes and environment using traditional methods. The ideal adoption "experiment" breaks the association between genetic background and rearing environments found in most family-based research. In practice, a well-designed adoption study minimizes selective placement (or estimates it based on measured aspects of the biological and rearing families and then controls for it statistically) and thus separates the confounding effects of genes, environment, and their interaction present in data from non-adoptive families (Plomin et al., 1997)

Interactions

One common model of gene-environment interaction postulates that genes influence sensitivity to the environment (Kendler & Eaves, 1986; Plomin, DeFries, McLearn, & McGuffin, 2008), so that interactions occur when genetic predispositions are expressed differently as a function of different environments. The ease of detecting interactions depends on the ranges of genetic background and environmental influences over which they occur. Figure 1 presents two possible interaction scenarios. In the left hand panel, a developmental outcome is graphed as the additive result of genetic background, rearing environment, and a multiplicative interaction that acts over the entire population range. Because the interaction is expressed across all levels of genes and environment, it is easier to detect. The right hand panel graphs a different type of interaction in which effects are detectable only at the shared extremes of the distribution: the "double deficits" and "double jackpots". Examples of such interactions may be difficult to detect due to small numbers of subjects found at the combined extremes of genetic backgrounds and rearing environments in population representative samples, and may require targeted sampling procedures. Adoption studies are one method that can be used to explore such interaction (Cadoret, Yates, Troughton, & Woodworth, 1995), but other methods including twin, epidemiological, and molecular genetic study designs are available as well.

One example of such an interaction occurs with children affected by phenylketonuria (PKU), a rare genetic disorder involving the inability to metabolize the amino acid phenylalanine, leading to an array of symptoms including mental retardation. Thanks to systematic genetic screening of newborns for this disorder, children who are diagnosed at birth can avoid its effects by maintaining a low phenylalanine diet (Blau, Hennermann, Langenbeck, & Lichter-Konecki, 2011). Negative symptoms should thus occur only for the subset of individuals who are both genetically susceptible and who do not maintain this special diet (i.e., the double deficit).

Assessment

Another issue concerns assessment. In animal studies, genetic background can be controlled by developing inbred or selected strains. Accurate knowledge regarding genetic background in humans is more problematic. We can make direct assessments through DNA collection, but few complex phenotypes (measured characteristics) are clearly derived from the known array of genotypes. We can make inferences from related measures of parents such as height, sex, or age at menarche to deduce something about genetic influences on strongly-related biological measures in children. Such parental phenotypes could be linked to the genetic background of their offspring if there is both additive genetic influence on the child measure and an association between the outcomes as measured at the parent's age and at the child's.

In the rigorous animal study unavailable to the human researcher, environments can be manipulated and finely measured—for example, the specific cage size, bedding material, food, and light-dark cycle. But in a human population, researchers are typically limited to observing and recording behaviors as they occur naturally. Direct measurements might include video-tape ratings, examiner reports, and geographic information system reports of neighborhood characteristics. We may solicit reports from objective observers such as teacher questionnaires or psychological evaluations. We often depend on parent-supplied information such as parental education, job titles, and other socioeconomic status indicators. And we may use measurement of the rearing parents such as IQ or other cognitive tests. Therefore, although objective assessment may be challenging, there are a number of ways in which we can approach this ideal.

Behavioral geneticists have developed methods based on family resemblance for inferring the importance of genetic and environmental influences on a wide range of human traits (e.g., physical, personality, and preferences) Figures 2 and 3 provide an illustration of the pathways by which biological families rearing parents contribute both genotype and rearing environment (Figure 2) are compared with adoptive families in which the birth parents contribute genotype and the adopting parents contribute environment (Figure 3). Examining different phenotypes results in varying inferences about the relative importance of genotype and environment and possible interactive effects can be assessed from similarity of adopted individuals to their adoptive and biological relatives, as well as the similarities between children and parents in non-adoptive families. A greater resemblance between child and birth parents than between child and adoptive parents suggests greater relative genetic influence. However, similarity to adoptive parents suggests the importance of familial environmental influences, those influences that are shared in common among family members (Plomin, et al., 2008). Environmental influences unique to an individual do not contribute to similarity among family members.

The relative importance of each of these influences varies among traits and at different time points in the lifespan. One interesting example of the results obtained with these models concerns developmental changes in cognitive abilities from infancy through adolescence (Plomin, Fulker, Corley, & DeFries, 1997). Adopted children, modeled in Figure 3, resemble their adoptive parents slightly in early childhood but not at all in middle childhood or adolescence. In contrast, during childhood and adolescence, adopted children become more like their biological parents--and to the same degree as children resemble their parents in non-adoptive families modeled in Figure 2. These findings indicate that genes which affect cognitive abilities in adulthood are not fully expressed until after childhood and that environmental factors contributing to differences in cognitive development are not correlated with parents' cognitive ability. Using this type of family resemblance data and models like those shown in Figures 2 and 3, we can estimate the importance of rearing environments and genetic background for behavior.

There are several longitudinal adoption studies being conducted (e.g., Deater-Deckard, Petrill & Wilkerson, 2001; Grotevant & McRoy, 1998; Lee, Grotevant, Hellerstedt, & Gunnar, 2006; Keyes, Sharma, Elkins, Iacono, & McGue, 2008; Riggins-Caspers, Cadoret, Knutson, & Langbehn, 2003), but most do not employ full adoption designs, are not limited to early placement, and begin later in childhood, adolescence, or adulthood. To our knowledge, only the recent Early Growth and Development Study (Leve et al., 2007) utilizes a prospective, full adoption design beginning in infancy, and its focus is limited to early childhood. Additionally, the birth and adoptive families interact with each other which is advantageous from some perspectives but does not provide a cleavage of environmental and genetic influences.

The Colorado Adoption Project

The Colorado Adoption Project (CAP) substantially overcomes many of the pitfalls described above. It is a longitudinal full-adoption study which includes birth parents, adoptive families, and a matched control sample. It was initiated in 1975 at the Institute for Behavioral Genetics (IBG), and is one of the largest and most comprehensive developmental adoption studies to date. In previous publications (Plomin & DeFries, 1983) and the first CAP book (Plomin & DeFries, 1985) the early history of the study and a partial sample were described. However, the final sample of 245 adoptive families (adopting parents, adopted children and siblings, as well as the biological parents of the adoptees) and 245 matched “control” families (non-adopting parents and their children) has not been previously described.

CAP staff recruited most of the birth mothers (and fathers if possible) through Denver Catholic and Lutheran Social Services, the two largest adoption agencies in the Rocky Mountain region. In the final months of enrollment, recruitment was supplemented by a few enrollments from other religious agencies. Those parents who planned on placing their children for adoption completed a three-hour battery of psychological measures, many of which were based on an earlier large-scale study of parents and children, the Hawaii Family Study of Cognition (DeFries, et al., 1974). Children did not leave the hospitals with their birth parents but rather were placed in brief stays in foster homes and then with their adopting parents at an average age of 29 days, with a range of 2 to 172 days.

Agency social workers contacted adoptive parents about possible participation in the CAP after formal adoption was completed. Twenty-five percent of the birth mothers enrolled did not place their children for adoption. Adopting families were not contacted in an additional 11% of potential cases usually due to out-of-state placements or family moves shortly thereafter. Of the 328 adoptive parents who were invited to participate, 75% agreed to do so. The adoptive parents completed the same measures as the birth parents. Their adopted child is then considered the proband (i.e., the index case) for subsequent study design and analyses. A control group of nonadoptive parents rearing their biological children was recruited through area hospitals and matched on the basis of proband gender and family demographics. As a result of Colorado demographics in the 70's and early 80's along with initial self-selection on the part of families working with the adoption agencies, 95% of the adopting parents and 90% of the birth parents reported that their race/ethnicity is non-Hispanic Caucasian, and nearly all the remainder are Hispanic. There were no transracial placements in the participating families, thus making this sample quite different from modern day adoption.

The first assessments of the children were begun in 1977 when the oldest CAP probands were a year old. Annual home visits were scheduled for all CAP probands and their younger siblings through age four. Follow-up phone calls to the parents kept the investigators in touch with the families at ages five and six. Children and the adoptive and control parents were tested again in-person at IBG facilities after the children had completed first grade. At that time, the parents were asked to complete a standard cognitive test, the WAIS-R (Wechsler, 1981) as a complement to the WISC-R (Wechsler, 1974) being given to their children. During the next stage of the CAP, interviews were conducted via phone calls both with parents and children at the children's ages 9–11; a novel telephone administration of cognitive assessment was developed and used at ages 9 and 10. This method has successfully enabled investigators to collect useful data cost-effectively and with less burden on participating families (Cardon, Corley, DeFries, Plomin, & Fulker, 1992; Kent & Plomin, 1987). Children were tested again in the laboratory at 12 years and by phone at ages 13, 14, and 15. Perhaps most importantly, the three-hour test battery previously administered to the

biological, adoptive, and control parents along with the WAIS-R was administered to the probands at age 16 as well as to their siblings. The CAP had thus come full circle, with children completing in late adolescence the same test battery their parents had completed 16 years earlier.

The first younger siblings in both types of families were enrolled and tested on a protocol identical to that of the probands. In 42 of the adoptive families, the younger sibling is also a proband in a separate birth parent dyad or triad with birth parents also tested on the enrollment battery. In five adoptive families a second younger sibling born to the adoptive parents was also followed longitudinally. In both adoptive and control families older siblings were invited to complete the parental enrollment battery at age 16 or older. As probands reached age 18, the study was expanded to include all siblings for additional longitudinal measures during late adolescence and early adulthood.

As part of a larger study of adolescent substance behaviors, the primary CAP subjects were asked questions regarding substance experimentation and use as part of their regular interviews at ages 12 through 16. After 16, these subjects and all their available siblings were administered detailed in-person structured interviews designed to yield DSM symptom counts and diagnoses of substance use and other psychological problems. This assessment was repeated at ages 21 and 25 for primary subjects who also completed the enrollment battery and WAIS-III (Wechsler, 1997) at age 21. Additional siblings, who had passed the initial age when this aspect of the project was launched, completed the psychological and substance problem interview twice at most.

Our adult assessments go beyond these problem behaviors. Beginning at age 18 for the primary subjects, and for the siblings at that age or up to age 30, we extended the protocols to include a social-demographic evaluation of normative development in early adulthood. We constructed a telephone interview based on Elder's (1998) methods to assess educational and status attainment, sexual activity initiation and union formation, and ongoing child-parent and sibling relationships. These interviews were conducted annually up to the age of 30, though due to timing and funding issues data are incomplete for some subjects. We are currently conducting one interview between the ages of 30 and 35 which incorporates most of these measures along with an additional assessment of the enrollment battery and WAIS III and a short form of the psychological problems and substance use interview.

Table 1 provides an overview of sample sizes for all family members at parent enrollment and for offspring during early childhood, middle childhood (about age 7), at least once during adolescent ages 9–15, at first administration of the adult battery to the offspring, and during continuation into adulthood. As can be seen by comparing columns for the offspring cells, more than 80% of both adopting and control families continued to participate when the proband child reached middle childhood. Efforts at re-enrollment resulted in an increase to nearly 90 and 95% respectively for adopting and control families at the “age 16” session.

Although adoption studies, like all human studies, cannot achieve an ideal experimental design, the CAP is *internally* representative in that the control parents were matched to adoptive parents on age, education, and occupation, and the probands' grandparents were similar to the parents of the adoptive parents for various measures of SES (see Table 2). Further, CAP families are somewhat *externally* representative for these SES measures; although means are higher than those for the US as a whole, they are comparable to those of the state and the time from which they were drawn and variances are similar to the US norms.

For comparison and testing of models, we also have a parallel study of more than 480 twin families participating in the Longitudinal Twin Study (LTS), recruited from the same state

and only slightly later (beginning in 1984); each study is useful for validating findings from the other. Figure 4 demonstrates that although the CAP parents are higher on these demographic measures than twin parents, they are only slightly so and have largely overlapping ranges.

Selective Placement

The CAP has also largely avoided the problems presented by selective placement. Historically, it was considered advisable to place children whose birth parents appeared to share characteristics such as appearance, personality, values and intelligence with prospective adopting parents (Hardy-Brown, Plomin, Greenhalgh, & Jax, 1979; Triseliotis, 1970). Currently, most placements are made by the birth parents themselves who are offered the opportunity to screen, either directly or through a social worker, prospective adopting parents. In the CAP, however, placements were made by social workers who did not attempt to match children with parents, except for a few specific attributes (Plomin & DeFries, 1985). In this sample, all children were placed for adoption through religion-based agencies with religious requirements for prospective parents. The Catholic agency required that at least adopting one parent be an active member of a Catholic parish and the Lutheran agency that both adopting parents be affiliated with any Protestant church. Additionally, prospective matches were based on similar height and contrasting location (e.g., children from southern Colorado placed in homes in northern Colorado.)

In summary, the CAP has many significant features which approximate an ideal developmental experiment. It is a full adoption design in which the adopted children were placed early, usually within the first month. It is longitudinal, with the child generation in both adoptive and control families being tested almost yearly from ages 1–26, again in their 30's and potentially well in to the future. It is multivariate with many measures of normal development, including cognition, personality, health, social competence, attitudes, and adjustment. It is isomorphic—at ages 16, 21, and in their 30's subjects in the child generation are tested using the same measures as their parents. And, it has had remarkably low attrition with nearly 90% of the sample still participating into early adulthood.

Measures of Adjustment

The CAP has collected adjustment data from its inception. Two personality measures, the 16 Personality Factor (Cattell, Eber, & Tatsuoka, 1970) and the EASI Temperament Survey (Buss & Plomin, 1975) along with a small selection of items regarding drinking, smoking and other problems were included in the parental battery. In infancy and early childhood, interviewers and parents rated the children on measures of behavior, such as Bayley's Behavior Record (Bayley, 1969) and Achenbach's Child Behavior Checklist (CBCL; Achenbach, 1991a; Achenbach and Edlebrock, 1983), and on temperament, such as the Colorado Childhood Temperament Inventory (CCTI; Rowe & Plomin, 1977) developed from the EASI. In middle childhood and adolescence, ratings on these measures were continued but were also supplemented with ratings from teachers and self-assessments. Teachers completed appropriate versions of the CCTI and CBCL-Teacher's Report Form (Achenbach, 1991b) along with a social competency measure (Merrell, 1991; Walker & McConnell, 1988). Children rated themselves on adjustment to school and life events in the first few years of education (Coddington, 1972; Graber, Brooks-Gunn & Warren, 1995; Rende & Plomin, 1991) and on measures of self-esteem (Harter, 1982), loneliness (Asher, Hymel, & Renshaw, 1984), depression (Kandel & Davies, 1982), and a children's version of the CCTI in later years. The psychological problems inventory administered at older ages, as described above, consisted of assessments of depressive, attention, conduct, and substance use disorders. The questionnaires associated with that interview included additional inventories of these disorders along with items about sexual behaviors. The adult social-

demographic assessments, begun at age 18, extended the items about sexual behaviors and added items about union formation, including partner aggression. For adopted subjects only, a questionnaire regarding their experience as adoptees and feelings of satisfaction and acceptance was administered in late adolescence and continued into adulthood.

Adjustment Interactions

Genes and Environment

One way to test for an interaction between genes and environment is to assess whether the impact of a pre-existing risk for a problem behavior, which has been shown to be under some genetic influence (e.g. Rhee & Waldman, 2002), is greater when coupled with an environmental risk (e.g., psychosocial stress resulting from divorce).

O'Connor, Caspi, DeFries, and Plomin (2003) examined an interaction involving the effect of family divorce and psychopathology on childhood behavior. Genetic risk was evaluated using a birth mother personality factor score, negative emotion (NE), which is highly correlated with measures of psychopathology (Krueger, Caspi, Moffitt, Silva, & McGee, 1996). O'Connor et al. (2003) found that adopted adolescents at age 12 scored high on CBCL internalizing and externalizing symptoms if their birth mother scored high on negative emotions (genetic risk) **and** their family experienced divorce (environmental risk). Their scores were elevated when compared to adoptees with the same genetic risk but no experience of divorce. Birth father data were not used as this was only available on a small portion of the sample.

Another study using CAP data explored the effect of divorce and the environmental influence of NE on problem behaviors in children. Rhea, Bricker, and Corley (2005) found no effect of rearing mothers' NE and parental separation on the child's later romantic relationships. However, if the rearing father scored high on NE, divorce was more likely by the time the child turned age 16--in both adopting and control families. Further, children from control families, who share with parents both genes and family environment, scored higher on NE than those from adoptive families sharing only the family environment. By age 21, the control children, who had greater overall risk from both genetic and environmental sources ("double deficits"), had a greater likelihood of problems in their own romantic relationships as evidenced by their scores on the partner aggression measure.

These two studies are consistent with the hypothesis that an interaction between genetic and environmental risk (i.e., parental separation and birth parent personality/psychopathology) contributes to children's manifestation of similar problem behaviors. A similar study of genetically uninformative subjects might have concluded that parental separation directly leads to problem behaviors in children. The adoption design allows for the exploration of alternative hypotheses involving both environmental and genetic causal explanations.

Sex and Adoption Status

A separate pair of studies examined interactions involving the adoption status and sex of individuals. Wadsworth et al. (1997) examined adjustment as measured by substance use/experimentation. Subjects included 260 adopted and 266 non-adopted individuals from the CAP sample in grades 7 through 12 who were asked about their use of tobacco, alcohol, marijuana, and other illicit substances. Adopted individuals overall were no more likely to experiment with substances than those who were not adopted. However, there were several significant interactions of adoption status by sex for reported substance use ($ps < .05$). For two of the interactions, more boys reported substance use than girls, and this sex difference was greater in the non-adopted than the adopted group. For six cross-over interactions more non-adopted boys used than non-adopted girls but adopted girls used the same or more than

adopted boys. Specifically, substance use was higher for adopted girls for cigarettes at grades 9 and 11, marijuana at grade 9, other drugs at grade 11, and one or more of any substance at grades 9 and 11.

Additionally, the prevalence of use for any substance was consistently higher among adopted compared with non-adopted girls from grades 8 through 11. Wadsworth et al. (1997) speculated that this discrepancy among girls may be due to decreased inhibition among adopted girls, and this may be related to some factor inherited from the biological parents. However, as the authors noted, it would be premature to conclude that adoption status alone could account for increased prevalence of substance use, especially considering that this accounted for a very small amount of the variability in the use of any given substance.

A similar interaction was found by Bricker et al. (2006) who examined adjustment in the extended CAP sample as measured by age at sexual initiation (age at first sex; AFS). Whereas AFS during middle to late adolescence is considered normative, early initiation (sometimes defined as age 14 or earlier) is considered problematic as it is associated with an increased risk for sexually transmitted infections and unwanted pregnancy due to lack or infrequent use of condoms and more sexual partners, and it is comorbid with other risky behaviors such as substance use and experimentation (AGI, 2006; Weinstock, Berman, and Cates, 2004; Jessor, 1991). In this study, 799 individuals from 143 adoptive and 160 non-adoptive families responded to questions at age 17 or later on the transition from adolescence to adulthood. As part of a behavioral genetic analysis to determine the relative importance of genetic and environmental factors on this problem behavior, four survival curves were constructed to determine if there were any differences in the prevalence of sexual onset beginning at age 12 for adopted and non-adopted males and females. On average, AFS for adoptees occurred six months earlier than for non-adoptees, and whereas AFS was similar for adopted males ($M = 16.8$ [$SD = 2.3$]) and non-adopted males ($M = 17.0$ [$SD = 2.2$]), adopted females ($M = 16.4$ [$SD = 2.2$]) initiated earlier than non-adopted females ($M = 17.4$ [$SD = 2.5$]). This one year difference between adopted and non-adopted females yields a moderate effect size of .42. Potential explanations for such a difference include genetically-influenced personality traits or earlier puberty leading to earlier sexual onset in both adoptees and biological mothers. Additionally, while psychological pressures associated with adoption might theoretically account for adolescent risky behavioral outcomes, the literature regarding greater psychological difficulties among adoptees is very mixed (Finley, 1999; Plomin and DeFries, 1985; Wierzbicki, 1993).

Adoption Status, Age at Menarche, and Religiosity

This final section presents results of previously unpublished analyses of AFS in the CAP sample that tested for interactions involving adoption status, age at menarche (AAM), and religiosity. Previous studies had found a relationship between early sexual behavior and early puberty in females (Ellis, 2004; Flannery, Rowe, & Gulley, 1993; Glynn et al., 2010; Mott et al., 1996) For example, Mott et al. (1996) found a correlation of .21 between age at menarche and age at first sex among mothers in a national sample of high risk females ascertained as adolescents, though no such relationship was found among their adolescent daughters.

Psychosocial and biological explanations are commonly cited to explain such a relationship. For example, early physical maturity may lead to greater social and psychological challenges relative to that which occurs at normative or later ages. Early maturers have less time to adjust their self-concept and are less developed cognitively than their later maturing peers at a time when they must adjust to expectations of society and their peer group that are based on physical maturity (Silbereisen & Kracke, 1997). Alternative explanations may

incorporate an effect of increasing levels of gonadal and adrenal hormones on depressive affect and aggression or, more specifically, on increased sexual interest and motivation. (Graber, Brooks-Gunn, & Warren, 2006). However, Rowe (2002) found that the relationship between age of menarche and sexual onset could be explained largely by overlapping genetic factors—for example, that genes which prepare girls for reproductive maturity also influence sexual behavior.

Age at Menarche—Among girls in the CAP sample, the correlation between AFS and AAM is .21 ($p < .01$), and for each year of delayed menarche, there is an approximate six month delay in sexual onset ($p < .01$). At the same time, early menarche appears to be more common among female adoptees (Brooker, Berenbaum, Bricker, Corley, & Wadsworth, 2012; Tuvemo, Gustafsson, & Proos, 1999; Virdis et al., 1998). In the CAP, female adoptees experienced menarche at an average age of 12.72 [$SD = 1.02$] compared with 13.06 [$SD = 1.02$] for non-adopted females, $t(279) = 2.777$, $p < .01$. This is a small difference and, as shown in Figure 5, the relationship between AFS and AAM was similar for adopted and non-adopted females.

Given these relationships among adoption status, menarcheal onset, and sexual onset, one might postulate that the risk for earlier AFS among female adoptees could be explained by their earlier menarche. In fact, Brooker et al. (2012) found that AAM partially mediated the relationship between adoption status and AFS among CAP females. Ellis (2004) has suggested that factors occurring earlier in childhood (e.g., difficult psycho-social adjustment due to father absence) may account for both outcomes, but that appears unlikely for these adoptees adopted in infancy with rearing fathers characteristically present.

Religiosity—Whereas earlier menarche may partially explain earlier AFS, religiosity may help to explain why some females have delayed sexual onset. As would be expected from the religious agencies' placement policies, nearly 90% of the fathers and 96% of the mothers in adopting families expressed having a religious affiliation, including Catholic (50%), Lutheran (20%) and other Christian (about 30%). In contrast, nearly 50% of the fathers and 43% of the mothers in the matched control families had no religious affiliation and 5% had non-Christian affiliations. As part of the questionnaire assessment in adolescence and early adulthood, subjects responded to questions assessing the importance of religious belief (e.g., belief in God) and practice (e.g., regular attendance at religious services) in their lives (Jessor & Jessor, 1977). We used the age 12 and age 16 assessments as these were the most complete and they bracketed the ages of early sexual initiation. The correlation between total religiosity at the two time points was .55 [95% CI: .46, .63] for females and .59 [95% CI: .54, .65] overall. Final religiosity scores were based on averaged sums of Likert-scale items from the two assessments. The correlation between religiosity and AFS for the female sample was .19 [95% CI: .06, .32] indicating that religiosity may be protective against early sexual initiation. The least religious group, defined as the lowest quartile with scores ranging from 5 to 11 were compared with the most religious group, defined by the top quartile with scores ranging from 23 to 25. The more religious group initiated sex, on average, at 17.71 [$SD = 2.57$] years old which was 1.16 years later than those who were less religious ($t(118) = 2.69$, $p < .01$). Contrary to expectations based on the adoption agency selection for religious parents, fewer of the adopted girls (47%) than the non-adopted girls (56%) were in the most religious quartile, though the difference was not significant ($\chi^2(df=1) = .745$, $p > .05$).

As with adoption status, we assessed the effect of religiosity on the relationship between AFS and AAM (see Figure 6). This illustrates the trend for earlier menarche to predict earlier sexual onset, but only among the least religious females. While it suggests a

protective effect of religiosity countering the effect of early menarche, this trend is not significant.

One caveat regarding the influence of religiosity is that adoptive parents in the CAP were chosen on the basis of religiosity so that the adopted children in this sample were more likely reared in religious homes. Therefore, the possible interaction involving religiosity in this sample may not necessarily extend to samples which are more representative of the distribution for religiosity in the general population.

Conclusions

All research designs, including adoption studies, have limitations. For example, most adoption studies share to some degree the problem of restricted range of environment which may affect both the findings and their applicability to the general population. In the CAP, one such restriction is that, due to the nature of the agencies from which the sample was acquired, there is little ethnic diversity and no transracial placements. Selective placement may affect findings but its presence can be detected and controlled for with sufficient information about both biological and rearing parents. In CAP, information about the biological parents' parents was used as a possible stand-in for selective placement of the biological parents due to their young ages, but in newer adoption studies, such as the one described by Ge et al. (2008), biological parents are assessed longitudinally and direct parent-offspring comparisons for a wider range of behaviors will be possible. CAP subjects had little to no contact with their birth parents. Reviewing data collected at an average age of 17.9 years for 216 subjects assessed between 1993–1997, only six subjects had met any biological relative, with three reporting that they had met a parent, and only one having more than annual contact with any biological relative. As adoption becomes more open, however, children will have more access to and more potential environmental influence from the biological parents, providing a less clean cleavage between genetic and environmental effects than the CAP.

In this paper we have illustrated how adoption studies may be used to disentangle genetic and environmental influences on behavioral development and to test for G-E interactions. In addition, we described the design of the Colorado Adoption Project, including subjects and measures, and provided two sets of examples demonstrating that children may be at greater risk for problem behavior if they have genetic liabilities coupled with either environmental stressors or a lack environmental protectors. In the first set of examples, citing previous CAP publications, we showed that conduct problems are more likely if children experience the genetic risk of inherited negative emotion personality traits along with family disruption such as divorce. In the second set of examples, we presented evidence that adoption status is a risk factor for both early substance use and early sexual initiation over and above the risk generated by early menarche, but also that religiosity is protective against early onset in this sample.

Due to its representativeness, absence of selective placement, inclusion of isomorphic birth parent data, and multiple measures from infancy through young adulthood, the Colorado Adoption Project may be regarded as a landmark study of behavioral development (cf. Rose, 1989). We have illustrated how adoption studies such as the CAP can provide unique information regarding the genetic and environmental etiologies of individual differences in adjustment, as well as the possible influence of gene by environment interactions on such important outcomes.

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FIGURE 1.

Examples of potential interactions between genetic background and rearing environment. On the left, there is an interaction across a wide range of a population distribution; on the right, there is an interaction only detectable at the extremes (color figure available online).

FIGURE 2.

Schematic of nuclear family with parents providing both genetic and environmental influences. Assortative mating (d) may result in parental similarity.

FIGURE 3.

Schematic of influences for an adopted child. Birth parents provide genetic influence and adopting parents provide environmental influence. Assortative mating (d) may result in parental similarity for both types of Parents.

FIGURE 4.

Comparison of CAP and LTS parent demographics. Black horizontal bars are medians, boxes on either side of the medians include the second and third quartiles, dotted vertical lines are cases within the 95% confidence interval, and circles are outliers.

FIGURE 5.
Age at first sexual initiation by age at menarche and adoption status.

FIGURE 6.
Age at first sexual initiation by age at menarche and religiosity.

Table 1

Number of subjects participating at 5 critical time points

	Initial	Middle Childhood Age 7	Adolescence Ages 9–15	Adult Battery“Age 16”	Age 18+
Birth Mother ¹	286	--	--	--	--
Birth Father ¹	60	--	--	--	--
Adopting Mother	242	--	--	--	--
Adopting Father	237	--	--	--	--
Control Mother	243	--	--	--	--
Control Father	244	--	--	--	--
Adopted Proband	245	201	208	215	201
Adopting Family Sibs	109	101	109	210 ²	195 ^{2, 3}
Control Proband	245	218	228	232	220
Control Family Sibs	117	110	117	260 ²	247 ^{2, 3}

¹Includes 41 mothers and 10 fathers whose children were placed as siblings.

²Includes older and younger siblings not invited to participate at ages 1–15, 110 in adopting and 148 in control families, respectively.

³Includes 17 siblings in 15 families who continued participation though the proband did not.

Table 2Occupational NORC Ratings of CAP Fathers¹ and a Denver Sample

	<i>X</i>	<i>SD</i>
Birth fathers	62.0	8.8
Adoptive fathers	75.0	9.0
Control Fathers	73.7	8.2
Birth fathers' fathers	73.4	8.4
Birth mothers' fathers	71.4	10.4
Adoptive fathers' fathers	69.3	9.2
Adoptive mothers' fathers	70.7	9.0
Control fathers' fathers	71.6	10.2
Control mothers' fathers	72.3	10.5
Denver random sample ²	71.3	7.8

¹Father data is used because many mothers of this era were not employed outside the home.

²From Crumpacker, et al. (1979).