J Quant Criminol (2012) 28:477–507
DOI 10.1007/s10940-011-9150-x

ORIGINAL PAPER

Genetic and Environmental Overlap between Low Self-Control and Delinquency

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Published online: 1 November 2011

Abstract Low self-control has emerged as a consistent and strong predictor of antisocial and delinquent behaviors. Using the twin subsample of the National Longitudinal Study of Adolescent Health (Add Health), genetic analyses were conducted to examine the genetic and environmental contributions to low self-control and offending as well as to their relationship with one another. The results revealed that low self-control and criminal behaviors are influenced by genetic and nonshared environmental factors with the effects of shared environmental factors being negligible. In addition, the co-variation between low self-control and criminal behaviors appears to be largely due to common genetic and nonshared environmental factors operating on both phenotypes. The implications of these findings on the current understanding of Gottfredson and Hirschi's general theory of crime are discussed.

Keywords Add Health · Behavioral genetics · Delinquency · Low self-control · Mx

Introduction

Central to Gottfredson and Hirschi's (1990) general theory of crime is the concept of self-control, which reflects an individual's ability to refrain from engaging in criminal activities

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and other immediately pleasurable behaviors (e.g., drinking, smoking, gambling, using drugs). Individuals with low self-control are characterized as being "impulsive, insensitive, physical (as opposed to mental), risk-taking, short-sighted, and nonverbal" (p. 90). Gottfredson and Hirschi argue that self-control emerges in early childhood as the result of effective parenting. Parents who consistently monitor their child's behavior, who recognize deviant behaviors, and who punish their child for misbehaving will instill self-control in their child.

While much research has evaluated potential environmental factors that influence variation in self-control, recent criminological research has begun to highlight the importance of genetic factors (Beaver et al. 2008a, d, 2009c; Wright et al. 2008; Wright and Beaver 2005). Several studies, using behavioral genetic methodology, reveal that genetic factors account for a moderate to large proportion of the variance in measures of self-control. This general finding holds using different samples and across various ages. For example, Beaver et al. (2009c) reported that 72% of the variance in low self-control was due to genetic factors in a sample of young twin children, with the remaining 28% attributable to nonshared environmental influences. In a sample of adolescents between the ages of 11–19, Beaver et al. (2008a) also found that 64% of the variance in low self-control was accounted for by genetic factors with the remaining 36% attributed to nonshared environmental factors.

Other disciplines, too, have examined how an individual's ability to control impulses, to manage risk tasking, to exact predictability of one's own life, to control emotional stimuli influence antisocial behavior. Indeed, several authors have noted the overlap between Gottfredson and Hirschi's description of low self-control and many of the indicators used to diagnose ADHD (Unnever et al. 2003; Cullen et al. 2008; Wright and Beaver 2005). Barkley (1997, 2006), for example, argues that low self-control and impulsivity are the main indicators of ADHD. Research has also shown that individuals with ADHD are less likely to exhibit self-control (Schweitzer and Sulzer-Azaroff 1995; Unnever et al. 2003) and are significantly more likely to exhibit criminal and analogous behaviors (Barkley et al. 2002; Pratt et al. 2002; Unnever and Cornell 2003; Unnever et al. 2003).

Several studies have assessed the heritability of constructs related to self-control, such as ADHD. These studies inform and advance the limited research on the genetic influences on Gottfredson and Hirschi's concept of self-control. For instance, Kuntsi et al. (2000) found that genetic factors explained 57% of the variance in a teacher-rated hyperactive subscale and 71% of the variance in a parent-rated impulsive-hyperactive subscale. Using a sample of toddlers, Price et al. (2001) found that hyperactivity was highly heritable, with estimates ranging from 0.79 to 0.83. Rietveld et al. (2003, 2004) reported heritability estimates for attention problems and overactive behavior at approximately 0.75. Furthermore, van den Oord et al. (1996) found that approximately 65% of the variance in overactive behavior was due to genetic factors. Several studies have also assessed attention problems and have found heritabilities of approximately 0.65–0.75 among preschoolers (Saudino et al. 2000), children between the ages of 5–9 years old (Gjone et al. 1996), and youth between the ages of 7–18 years old (Edelbrock et al. 1995; Schmitz et al. 1995; Hudziak et al. 2000). Further, a meta-analysis by Nikolas and Burt (2010) included 79 twin and adoption studies and found that both inattention and hyperactivity were influenced by genetic factors with 71 and 73% of the variance being attributed to genetics, respectively. Taken together, the available evidence indicates that low self-control and other closely related constructs appear to be moderately to strongly influenced by genetic factors.

Antisocial Behaviors

While Gottfredson and Hirschi (1990) claim that the magnitude of the genetic effect on delinquency is near zero, hundreds of twin studies have shown that antisocial behaviors, and delinquent behaviors in particular, are influenced by genetic factors (Rhee and Waldman 2002; Moffitt 2005). A meta-analysis by Rhee and Waldman (2002) estimated that genetic factors (i.e., additive and nonadditive) accounted for 41% of the variance in antisocial behaviors with the remaining 16 and 43% of the variance being attributed to shared and nonshared environmental factors, respectively. Researchers have also investigated etiological differences within antisocial behaviors. For example, a meta-analysis by Burt (2009) distinguished between aggressive and nonaggressive forms of antisocial behaviors to examine the genetic, shared, and nonshared environmental influences on these types of antisocial behavior. Her results revealed that aggressive forms of antisocial behavior could be attributed mainly to genetic (65%) and nonshared environmental (30%) factors. On the other hand, 48, 18, and 34% of the variance in nonaggressive forms of antisocial behaviors were accounted for by genetic, shared, and nonshared environmental influences, respectively. It is evident that shared environmental influences were more pronounced in nonaggressive forms of antisocial behaviors.

Relationship Between Low Self-Control and Antisocial Behaviors

While causes of self-control and delinquency are topics of much debate, there is little doubt that self-control is a potent predictor of criminal and analogous behaviors (Pratt and Cullen 2000). Low self-control, and similar constructs such as ADHD, have been identified as significant predictors of academic performance (Duckworth and Seligman 2005), self-reported delinquency (Lynam et al. 1993), general delinquency (McGloin et al. 2004), arrests (Unnever et al. 2003), as well as minor and serious juvenile offending (Cauffman et al. 2005). There is quite a bit of empirical evidence to suggest that low self-control is also associated with various types of analogous or "imprudent" behaviors, including substance use/abuse (Baron 2003; Nakhaie et al. 2000; Tangney et al. 2004; Vazsonyi et al. 2001), accidents (Junger and Tremblay 1999), academic dishonesty (Cochran et al. 1998; Jones and Quisenberry 2004), cutting classes (Arneklev et al. 1998; Gibbs and Giever 1995), bullying (Unnever and Cornell 2003), pathological gambling (Jones and Quisenberry 2004), sexual promiscuity (Jones and Quisenberry 2004), and risky driving (Forde and Kennedy 1997; Junger et al. 2001).

Behavioral genetic methodology can examine whether the consistent relationship found between low self-control and criminal behavior can be attributed to common genetic and/or environmental factors operating on both phenotypes. While no study has yet to examine whether the observed correlation between self-control and offending is due to similar genetic and/or environmental factors, a few studies from other disciplines have examined the covariation between constructs analogous to low self-control and various forms of antisocial behaviors. For example, using teacher and parental reports of child behavior from the *FinnTwin12* data, Vierikko et al. (2004) found strong genetic correlations (0.44–0.77) between hyperactivity-impulsivity and aggression. These results imply that, to a large extent, the same genes affected levels of hyperactivity-impulsivity and aggression in a sample of youth aged 11–12 years old.

Silberg et al. (1996) assessed the genetic and environmental contributions to the co-occurrence of hyperactivity and oppositional/conduct problems in a sample of young twins aged 8–11 ($N = 1{,}197$ twin pairs). Their results revealed a genetic correlation of 1.0

between the two phenotypes, implying that the same set of genes are influencing hyperactivity and oppositional/conduct problems. Two years later, Nadder et al. (1998) expanded upon Silberg et al.'s (1996) study by using a multi-dimensional measure of ADHD rather than a measure of hyperactivity. Their analytical sample included 900 twin pairs from the Virginia Twin Study of Adolescent Behavioral Development aged 7–13 years old. The results from their bivariate genetic models revealed that the covariation between ADHD and oppositional/conduct problems was moderately attributable to common genetic factors (50%).

The extent to which the covariation between attention problems and delinquency could be the product of the same genetic and/or environmental factors was examined by Schmitz and Mrazek (2001) using a sample of 207 twin pairs aged 4–11 years old. Their results again revealed strong genetic correlations between attention problems and delinquent behaviors (0.65) and between attention problems and aggression (0.76). Using these genetic correlations, further analyses revealed that 79% of the phenotypic correlation found between attention problems and delinquent behaviors was due to the same genetic factors. Furthermore, 70% of the phenotypic correlation found between attention problems and aggression was attributed to the same genetic factors operating on both traits.

Current Study

Research has shown that both low self-control and delinquent/antisocial behaviors are influenced by genetic and environmental factors. Moreover, studies have also revealed that common genetic factors are partially to fully responsible for the co-occurrence of constructs related to Gottfredson and Hirschi's concept of low self-control and antisocial behaviors. The purpose of the current study is to examine the genetic and environmental contributions to the covariation between low self-control and offending in adolescence and adulthood. Furthermore, several studies have examined violent and nonviolent crimes separately (e.g., Mednick et al. 1984; Bohman et al. 1982; Cloninger and Gottesman 1987) and a recent meta-analysis by Burt (2009) has shown that genetic effects are stronger in aggressive forms of antisocial behaviors and that shared environmental effects are more pronounced in nonaggressive forms of antisocial behaviors. As such, the current study also makes the distinction between violent and nonviolent offending in order to assess whether the genetic and environmental factors differ based on the seriousness of offending.

Methods

Sample

Data for the current study come from the National Longitudinal Study of Adolescent Health (Add Health). Add Health is a longitudinal, nationally representative study of American adolescents in grades seven through twelve. Three waves of data were collected over a 7 years span starting in September 1994 to December 1995, when the youths were between the ages of 11–19. Approximately 1 year later, between 1995 and 1996, the second wave of data was collected when participants ranged from 12 to 20 years old. Finally, the third wave of data collection, administered between August 2001 and April 2002, assessed participants when they were young adults between the ages of 18–26.

This longitudinal design allows researchers to study participants over time from adolescence into adulthood. As such, the current study assesses the genetic and environmental contributions to the covariation of low self-control and offending across the three time periods.

During wave I, approximately 90,000 youths from the selected 132 schools completed the in-school questionnaire (Chantala and Tabor 1999). The survey assessed various domains, such as demographics, health and emotional status, peer relationships, family dynamics, and school-related activities. A random subsample of 20,745 youths was then asked to complete the in-home interview between April and December of 1995. At this stage, youths and their caregivers ($N = 17{,}700$) were interviewed about a variety of topics, such as family dynamics, neighborhood characteristics, school activities, romantic relationships, and antisocial behaviors. Youths from the in-home interviews were then followed up approximately 1 year later for the second wave of data collection ($N = 14{,}738$). Most of the items found in the wave II questionnaire were similar to those found in wave I, such as drug and alcohol use, peer groups, sexual experiences, emotional and physical health, and delinquent behaviors. Participants were then re-interviewed a third time approximately 6 years later ($N = 15{,}170$). Since most of the respondents were now young adults, the questions were adjusted to reflect their new life experiences, while simultaneously trying to obtain information regarding transitional experiences from adolescence to adulthood. Therefore, topics such as marriage, employment, education, childrearing, and criminal behaviors were addressed in the wave III questionnaire.

It is important to note that during the wave I in-school survey, respondents were asked if they had any siblings that were also enrolled in grades seven through twelve. If the participant responded affirmatively, the Add Health research team then automatically included their sibling(s) into the wave I in-home interviews. This genetic subsample at wave I consisted of twins ($N = 1{,}568$), full siblings ($N = 2{,}502$), half-siblings ($N = 884$), and non-related siblings living in the same home, such as adopted siblings, foster children, and step-siblings ($N = 1{,}884$) (Harris et al. 2006).

The current study included information on 1,568 individual twins ($N = 784$ twin pairs).[1] Two methods were used to determine zygosity: self-report and DNA analysis. First, in waves I and II, twins self-reported their zygosity using four questions related to their similarities in physical characteristics as well as their experiences with identity confusion. In wave III, samples of buccal cells were collected for DNA analysis. This allowed researchers to positively determine zygosity by comparing the DNA of twin 1 to the DNA of twin 2. If a twin pair was identical for five or more genetic markers, they were classified as monozygotic twins. On the other hand, if the twin pair differed on one or more genetic markers, they were classified as dizygotic twins. The results from the DNA analysis demonstrated that 92% of the participants had correctly self-identified their zygosity. In sum, these two methods positively identified 307 MZ and 452 DZ twin pairs, leaving 25 twin pairs with uncertain zygosity (Harris et al. 2006). For the purposes of this study, twins with uncertain zygosity were classified as dizygotic twins. This is a conservative approach since it increases the likelihood of overestimating the environmental effects on behaviors.

[1] There was an approximately even distribution of males (48%) and females (47%), with 6% of the cases missing information on gender. Also, approximately 60% of the sample was White, 23% was Black, 10% was classified as other, and 6% was unknown.

Measures

Low Self-Control at Wave I

Since the Add Health data does not contain a direct measure of self-control, many studies have included between 5 and 8 items to capture an individual's level of self-control (Beaver 2008; Beaver et al. 2008b, c, d, 2009c; Boutwell and Beaver 2008; DeLisi et al. 2008; McGloin and O'Neill Shermer 2009; Perrone et al. 2004; Wright et al. 2008). Following this approach, the current study included five items that tap into the degree to which participants get along with their teachers and other students, keep their mind focused, get their homework done, and pay attention in school. A complete list of the questions included in the measure of low self-control at wave I along with their respective response categories are provided in the Appendix. Using MPLUS 6.0, the five items were subjected to a confirmatory factor analysis.[2] Using the mean adjusted weighted least squares estimator,[3] the results revealed that the five items load on a single factor[4] ($\chi^2 = 14.56, p = 0.006$, CFI = 0.997, TLI = 0.992, RMSEA = 0.042). These items were then summed together so that higher values reflect greater levels of low self-control (alpha = 0.71). The range for low self-control at wave I was 0 to 19 with a mean of 4.87 (SD = 3.36).

Low Self-Control at Wave II

The measure of low self-control at wave II included the same five items included in the measure of low self-control at wave I. That is, the degree to which respondents get along with their teachers and other students, keep their mind focused, get their homework done, and pay attention in school. Including the same items at wave II was done to maintain consistency in the measure of low self-control over time. The five items at wave II were also subjected to a confirmatory factor analysis. Using the mean adjusted weighted least squares estimator, the results revealed that the five items load on a single factor[5] ($\chi^2 = 6.58$, $p = 0.16$, CFI = 0.999, TLI = 0.997, RMSEA = 0.022). These items were then summed together, with higher values reflecting greater levels of low self-control (alpha = 0.67). The range for low self-control at wave II was 0–17 with a mean of 4.61 (SD = 3.16).

To establish measurement invariance in the latent constructs of low self-control at waves I and II, we examined whether there was invariance in factor loadings (weak factorial invariance) and in the thresholds (strong factorial invariance).[6] First, we estimated a baseline model, which fit the data relatively well ($\chi^2 = 183.837$, $df = 27$, RMSEA = 0.061, CFI = 0.980, TLI = 0.968). Next, we estimated a model that holds the

[2] The model is deemed a good fit to the data if the Comparative Fix Index (CFI) is $\geq$0.95, the Tucker Lewis Index (TLI) is $\geq$0.95, and the Root Mean Squared Error of Approximation (RMSEA) is $\leq$0.06.

[3] The mean adjusted weighted least squares estimator is appropriate for categorical indicators, such as those included in the measures of self-control in this study.

[4] A covariance was added between the error terms for the measures of "getting into trouble with teachers" and "getting into trouble with other students" at wave I.

[5] A covariance was added between the error terms for the measures of "getting into trouble with teachers" and "getting into trouble with other students" at wave II.

[6] This is accomplished by estimating a series of models where the factor loadings and thresholds are fixed or freed, and then the models are compared with the Santorra Bentler difference of Chi-square test.

factor loadings equal across time. The weak factorial invariance model provides a good fit to the data ($\chi^2 = 163.124$, $df = 31$, RMSEA = 0.054, CFI = 0.983, TLI = 0.976) and a difference of Chi-square test shows that it provides a significantly better fit to the data than the baseline model (difference of χ^2 test = 15.591, $df = 4$, $p = 0.02$). Following this, we estimated a model that fixes the thresholds of the same items across time. This model provides a good fit to the data ($\chi^2 = 190.061$, $df = 49$, RMSEA = 0.044, CFI = 0.982, TLI = 0.984) and a difference of Chi-square test shows that fixing the thresholds across time does not significant worsen the fit of the model (difference of χ^2 test = 7.84, $df = 22$, $p = 0.98$). Overall, the results indicate that there is strong factorial invariance in the measures of self-control from wave I to wave II.[7]

Low Self-Control at Wave III

A measure of low self-control at wave III was created using 7 items derived from the self-reported questionnaire. The items used to create the measure of low self-control at wave III differ from those used at waves I and II. This is because the participants were now young adults and Add Health no longer asked them school-related questions. Rather, the seven items included at wave III assess the degree to which respondent's liked to try new things, their desire for excitement, their attention span, etc., with response categories ranging from 0 (not true) to 4 (very true). A complete list of items included in this measure is provided in the Appendix. Confirmatory factor analysis with the mean adjusted weighted least squares estimator revealed that the seven items load on a single factor[8] ($\chi^2 = 74.41$, $p < 0.001$, CFI = 0.994, TLI = 0.990, RMSEA = 0.063). These items were then summed together, with higher scores reflecting higher levels of low self-control (alpha = 0.84). The range for the measure of low self-control at wave III was 0–28 and the mean was 10.25 (SD = 6.58).

Overall, the measures of low self-control at all three waves have reasonable internal consistency, ranging from 0.67 to 0.84, and correlate across waves modestly. The correlations between low self-control from waves I and II was $r = 0.47$ ($p < 0.001$); between waves II and III was $r = 0.21$ ($p < 0.001$) and between I and III was $r = 0.20$ ($p < 0.001$).[9] We note that the time difference between waves I and II was 1 year, between waves II and III was 6 years, and between waves I and III was 7 years.

Overall Delinquency

Overall delinquency was measured at all three waves of data collection. The fourteen items included in the measure of overall delinquency at waves I and II were the exact same. At wave III, however, some of the questions (i.e., 4/14) were adjusted in order to capture

[7] More specifically, the presence of weak factorial invariance suggests that the interpretation of the items does not vary over time, and that the factors are in the same metric over time (i.e., a one unit change in the factor score corresponds the same amount of change in the observed variable over time). The presence of invariance in the thresholds suggests that the response choices are interpreted the same across time.

[8] A covariance was added between the error terms for the measures of "look for exciting things to do" and "try new things just for fun or thrills" at wave III.

[9] Many studies have found self-control to be moderately to highly stable (Arneklev et al. 1998; Hay and Forrest 2006). The low between wave correlations reported here could be the result of several different factors, including but not limited to, (1) unique sampling variance specific to the Add Health, (2) the time elapsed between waves—the time between wave I and wave III is 7 years, (3) items included in the measures at waves I and II were not the same as those included at wave III, and/or (4) compounded measurement error across waves, as error over time reduces stability estimates.

antisocial behaviors that were more age appropriate. For example, a respondent painting graffiti is no longer an age-appropriate question to ask an individual between the ages of 18–26. Instead, questions such as deliberately writing bad checks were added in wave III. Overall, at all three waves of data collection, participants were asked how often, in the past 12 months, they had engaged in fourteen different age-appropriate delinquent activities. A complete list of the items included in the measures of overall delinquency at waves I, II, and III is provided in the Appendix.

At each wave, the fourteen items were summed together to create an overall delinquency scale, with higher scores indicating greater delinquent/criminal involvement (wave I alpha = 0.84; wave II alpha = 0.81; wave III alpha = 0.73). Scores for the measures of overall delinquency at wave I ranged from 0 to 40 with a mean of 2.48 (SD = 4.22). At wave II, the scores ranged from 0 to 27 with a mean of 1.56 (SD = 3.14). Finally, at wave III the score ranged from 0 to 22 with a mean of 0.69 (SD = 1.83). A frequency distribution of the measures of overall delinquency at all three waves revealed a positive skew. Therefore, all measures of overall delinquency were log transformed ($\log(x + 1)$) prior to being included in the analyses. These measures of overall delinquency have been used in prior research (Haynie and Osgood 2005; Haynie et al. 2005; Haynie 2001, 2002; Pearce and Haynie 2003).

Nonviolent Delinquency

Of the fourteen items included in the overall delinquency measures at waves I, II, and III, eight of them tap into nonviolent forms of delinquency (see Appendix). The measure of nonviolent delinquency at waves I and II include the exact same eight questions, with respondents indicating how often, in the past 12 months, they had participated in various forms of nonviolent delinquent activities, such as painting graffiti and damaging property. However, of these eight items included in the measures of nonviolent delinquency at waves I and II, only five were included in the wave III nonviolent delinquency scale. The other three items were replaced with more age-appropriate questions related to nonviolent activities, such as using someone else's credit or bank card without their permission or knowledge, and deliberately writing a bad check.

For all measures of nonviolent delinquency, the response categories ranged from 0 (i.e., never) to 3 (i.e., five or more times). These items were then summed together to create a nonviolent delinquency scale at waves I, II, and III. Higher scores indicate a greater level of involvement in nonviolent delinquent activities (wave I alpha = 0.78; wave II alpha = 0.77; wave III alpha = 0.66). The mean for the measure of nonviolent delinquency at wave I is 1.46 with a standard deviation of 2.81 (range = 0–24), the mean at wave II is 1.02 with a standard deviation of 2.34 (range = 0–24), and finally at wave III the mean is 0.49 with a standard deviation of 1.36 (range = 0–15). The positively skewed distribution of the measures of nonviolent delinquency at all three waves required that each measure be log transformed ($\log(x + 1)$) prior to being included in the analyses.

Violent Delinquency

As mentioned above, fourteen items make up the overall delinquency measures at waves I, II, and III. While eight of these items are related to nonviolent delinquency, the remaining six items assessed the participants' involvement in violent delinquent behaviors (see Appendix). Waves I and II asked participants to self-report how often, in the past year, they'd participated in the exact same six violent behaviors (e.g., shooting or stabbing someone and pulling a knife on someone). At wave III, however, the item measuring the frequency of serious physical fighting was replaced with an item measuring the frequency of using a weapon in a fight. Therefore, five of the six items used in creating the measure of violent delinquency at wave III were identical to those included at waves I and II.

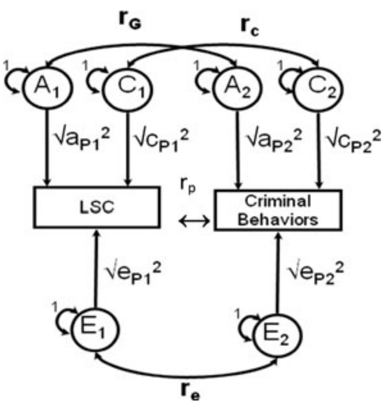
The responses to these six questions were then summed together to create a measure of violent delinquency at waves I, II, and III, with higher scores indicating greater levels of violent delinquent involvement (wave I alpha = 0.75; wave II alpha = 0.72; wave III alpha = 0.52). The mean for violent delinquency at wave I is 1.02 (SD = 1.97) with a range of 0 to 16. At wave II, the scores ranged from 0 to 13 with a mean of 0.56 (SD = 1.34). Finally, at wave III the scores ranged from 0 to 7 with a mean of 0.20 (SD = 0.70). Again, the measures of violent delinquency at waves I, II, and III were log transformed ($\log(x + 1)$) prior to being included into the analyses due to their positively skewed frequency distributions.

Analysis

Intraclass correlations for MZ and DZ twin pairs were calculated for all measures of interest. If the intraclass correlation of MZ twin pairs is higher than that of DZ twin pairs, this suggests that there are genetic factors influencing the variable of interest. Next, cross-twin/cross-trait correlations were calculated for MZ and DZ twin pairs in order to assess whether the phenotypic correlation between the two variables is due to common genetic factors. This is accomplished by correlating twin 1's self-control score with his/her co-twin's delinquent behavior score (as well as twin 1's delinquency score with twin 2's self-control score). If the cross-trait/cross-twin correlation is higher for MZ twins compared to DZ twins, this suggests that genetic factors may partially explain the correlation between the two variables.

Bivariate genetic analyses were then conducted using the structural equation modeling program Mx (see Fig. 1). These analyses allow for the decomposition of the correlation between low self-control and offending (r_P) into the proportion that is due to the same genetic (A), shared environmental (C), and nonshared environmental (E) factors (Neale and Cardon 1992). Several estimates are needed for these calculations, including the genetic (i.e., a^2_{P1}, a^2_{P2}), shared environmental (i.e., c^2_{P1}, c^2_{P2}), and nonshared environmental (i.e., e^2_{P1}, e^2_{P2}) effects on both phenotypes as well as the genetic (r_G), shared (r_c), and nonshared environmental correlations (r_e). The values for r_G, r_c, and r_e represent the extent to which

Fig. 1 Bivariate genetic model



genetic, shared, and nonshared environmental influences overlap between the two phenotypes, regardless of their individual parameter estimates. The equation to calculate the proportion of the correlation between low self-control and offending that is attributed to the same genetic factors is as follows:

$$\left(\sqrt{a_{P1}^2} * r_G * \sqrt{a_{P2}^2}\right)/rp$$

a_{P1}^2: the proportion of the variance in low self-control that is due to genetics; r_{G}: the genetic correlation; a_{P2}^2: the proportion of the variance in delinquency that is due to genetics; r_{P}: the correlation coefficient between low self-control and delinquency.

The proportion of the correlation between low self-control and delinquency attributed to the same shared and nonshared environmental factors are calculated in a similar manner. It is important to note that the estimates used in the above equation are derived from the best fitting genetic model. The best fitting model is determined by first estimating the full ACE model followed by individually dropping the *A* (i.e., genetic) and *C* (i.e., shared environment) parameters. The goodness-of-fit of these submodels are then compared to the full model by examining the Chi-squared (χ^2) statistics, the probability values, and the Akaike's Information Criterion (AIC; Akaike 1987). For example, a submodel, such as AE, is considered a better fitting model compared to ACE if the Chi-square test is nonsignificant and the AIC value is a large negative value. These results would imply that setting the *C* parameters to zero does not significantly decrease the fit of the model. Therefore, it would be concluded that the AE submodel is a more parsimonious model and the estimates from this model would then be used to calculate of the proportion of the correlation between two variables that is attributed to the same genetic, shared, and nonshared environmental factors.

Results

Table 1 reveals that most of the intraclass correlations and cross-twin/cross-trait correlations are stronger for MZ twin pairs compared to DZ twin pairs.[10] These results suggest that genetic factors are influencing both self-control and delinquent/criminal behaviors as well as the co-variation between the two. Furthermore, the correlations between low self-control and the measures of delinquency at wave I are all statistically significant (Table 2). Table 3 reveals that the proportion of the variance in low self-control at wave I attributed to genetic effects is 45% and to nonshared environmental factors is 55%. For overall, nonviolent, and violent delinquency at wave I, 58, 53, and 53% of the variance is due to genetic factors, respectively. The remaining variance in the three measures of delinquency is attributed to nonshared environmental factors. Following the procedures described in the methods section, it was calculated that between 82 and 83% of the correlation between low self-control and the measures of delinquency at wave I is due to common genetic factors while the remaining 17–18% is due to common nonshared environmental factors (Table 2).

At wave II, the phenotypic correlations between low self-control and the three measures of delinquency are all statistically significant (Table 2). Table 4 reveals that the proportion of the variance in low self-control at wave II accounted for by genetic factors is 33% and by nonshared environmental factors is 67%. For overall, nonviolent, and violent delinquency at

[10] With a few exceptions.

Table 1 Intraclass correlations and cross-trait/cross-twin correlations (MZ twin pairs above the diagonal and DZ twin pairs below the diagonal)

	Low self-control		Delinquency	
	Twin 1	Twin 2	Twin 1	Twin 2
Wave I				
Low self control				
Twin 1	1	0.45***	0.30***	0.33***
Twin 2	0.24***	1	0.21***	0.35***
Overall delinquency				
Twin 1	0.35***	0.21***	1	0.58***
Twin 2	0.16**	0.41***	0.31***	1
Low self-control				
Twin 1	1	0.45***	0.31***	0.35***
Twin 2	0.24***	1	0.18**	0.33***
Nonviolent delinquency				
Twin 1	0.33***	0.19***	1	0.52***
Twin 2	0.16**	0.39***	0.31***	1
Low self-control				
Twin 1	1	0.45***	0.22***	0.19**
Twin 2	0.24***	1	0.19**	0.26***
Violent delinquency				
Twin 1	0.26***	0.17**	1	0.53***
Twin 2	0.10*	0.30***	0.29***	1
Wave II				
Low self control				
Twin 1	1	0.35***	0.34***	0.18**
Twin 2	0.14*	1	0.08	0.36***
Overall delinquency				
Twin 1	0.35***	0.17**	1	0.40***
Twin 2	0.14**	0.34***	0.34***	1
Low self-control				
Twin 1	1	0.35***	0.31***	0.19**
Twin 2	0.14*	1	0.04	0.30***
Nonviolent delinquency				
Twin 1	0.33***	0.17**	1	0.38***
Twin 2	0.15**	0.33***	0.32***	1
Low self-control				
Twin 1	1	0.35***	0.28***	0.01
Twin 2	0.14*	1	0.09	0.27***
Violent delinquency				
Twin 1	0.26***	0.15**	1	0.22***
Twin 2	0.05	0.20***	0.24***	1
Wave III				
Low self control				
Twin 1	1	0.50***	0.19**	0.17*

Table 1 continued

	Low self-control		Delinquency	
	Twin 1	Twin 2	Twin 1	Twin 2
Twin 2	0.11	1	0.14*	0.28***
Overall delinquency				
Twin 1	0.32***	0.07	1	0.34***
Twin 2	0.12*	0.38***	0.22***	1
Low self-control				
Twin 1	1	0.50***	0.11	0.14
Twin 2	0.11	1	0.09	0.24***
Nonviolent delinquency				
Twin 1	0.27***	0.05	1	0.37***
Twin 2	0.14*	0.32***	0.13*	1
Low self-control				
Twin 1	1	0.50***	0.20**	0.11
Twin 2	0.11	1	0.17*	0.21**
Violent delinquency				
Twin 1	0.29***	0.06	1	0.19**
Twin 2	0.00	0.32***	0.19**	1

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

Table 2 Phenotypic correlations between low self-control and delinquency (r_p) and the percent of the correlation attributed to the same genetic (A), shared environmental (C), and nonshared environmental influences (E) at waves I, II, and III

	r_p	A (%)	C	E (%)
Wave I				
LSC and overall delinquency	0.36***	83	–	17
LSC and nonviolent delinquency	0.34***	82	–	18
LSC and violent delinquency	0.26***	83	–	17
Wave II				
LSC and overall delinquency	0.35***	49	–	51
LSC and nonviolent delinquency	0.32***	55	–	45
LSC and violent delinquency	0.25***	32	–	68
Wave III				
LSC and overall offending	0.30***	67	–	33
LSC and nonviolent offending	0.24***	67	–	33
LSC and violent offending	0.26***	62	–	38

*** $p < 0.001$

wave II, the proportion of the variance accounted for by genetic effects is 46, 44, and 30%, respectively. Nonshared environmental factors accounted for the remaining proportion of the variance in all three measures of delinquency. Following the calculations described above, it was found that between 32 and 55% of the correlation between low self-control and the

Table 3 Bivariate analyses of low self-control and delinquency at wave I (parameter estimates and 95% confidence interval)

Model fit		Change statistics				Variable 1		
	−2lnl	*df*	ΔX^2	*P*	AIC	*A*	*C*	*E*
						Low self-control I		
ACE	8611.49	2,887			2,837.49	0.42 (0.19–0.52)	0.02 (0.00–0.20)	0.55 (0.48–0.65)
CE	8,642.21	2,890	30.72	0.00	24.72	–	0.32 (0.25–0.38)	0.68 (0.62–0.75)
AE	8,611.85	2,890	0.35	0.95	−5.65	0.45 (0.36–0.53)	–	0.55 (0.47–0.64)
						Low self-control I		
ACE	8,435.76	2,891			2,653.76	0.43 (0.19–0.52)	0.02 (0.00–0.20)	0.55 (0.47–0.65)
CE	8,457.78	2,894	22.02	0.00	16.02	–	0.32 (0.25–0.39)	0.68 (0.62–0.75)
AE	8,436.95	2,894	1.19	0.76	−4.81	0.45 (0.36–0.53)	–	0.55 (0.47–0.64)
						Low self-control I		
ACE	7,669.87	2,892			1,885.87	0.43 (0.18–0.52)	0.02 (0.00–0.21)	0.56 (0.48–0.65)
CE	7,693.19	2,895	23.32	0.00	17.32	–	0.32 (0.25–0.38)	0.68 (0.62–0.75)
AE	7,670.51	2,895	0.64	0.89	−5.36	0.45 (0.36–0.53)	–	0.55 (0.47–0.64)

Model fit		Variable 2			*r*		
	−2lnl	*A*	*C*	*E*	*g*	*c*	*e*
		Overall delinquency I					
ACE	8611.49	0.52 (0.31–0.64)	0.05 (0.00–0.22)	0.43 (0.36–0.51)	0.55 (0.32–0.87)	1.00 (−1–1)	0.13 (0.02–0.24)
CE	8,642.21	–	0.42 (0.35–0.48)	0.58 (0.52–0.65)	–	0.59 (0.45–0.71)	0.23 (0.15–0.30)
AE	8,611.85	0.58 (0.50–0.64)	–	0.42 (0.36–0.50)	0.58 (0.47–0.70)	–	0.12 (0.02–0.23)
		Nonviolent delinquency I					
ACE	8,435.76	0.41 (0.18–0.58)	0.10 (0.00–0.28)	0.49 (0.41–0.57)	0.56 (0.25–0.97)	1.00 (−1–1)	0.13 (0.02–0.24)
CE	8,457.78	–	0.39 (0.32–0.45)	0.61 (0.55–0.68)	–	0.57 (0.44–0.71)	0.21 (0.14–0.29)
AE	8,436.95	0.53 (0.45–0.59)	–	0.47 (0.41–0.55)	0.57 (0.45–0.69)	–	0.12 (0.02–0.22)

Table 3 continued

Model fit		Variable 2			*r*		
	−2lnl	*A*	*C*	*E*	*g*	*c*	*e*
		Violent delinquency I					
ACE	7,669.87	0.44 (0.21–0.59)	0.07 (0.00–0.26)	0.48 (0.41–0.57)	0.39 (0.05–0.80)	1.00 (−1–1)	0.10 (−0.01–0.21)
CE	7,693.19	–	0.39 (0.32–0.45)	0.61 (0.55–0.68)	–	0.44 (0.29–0.58)	0.16 (0.09–0.24)
AE	7,670.51	0.53 (0.45–0.59)	–	0.47 (0.41–0.55)	0.44 (0.31–0.56)	–	0.09 (−0.01–0.20)

Note: 95% confidence interval not including 0 indicates a significant parameter at $p < 0.05$

Table 4 Bivariate analyses of low self-control and delinquency at wave II (parameter estimates and 95% confidence interval)

Model fit		Change statistics				Variable 1		
	−2lnl	*df*	ΔX^2	*p*	AIC	*A*	*C*	*E*
						Low self-control II		
ACE	7,022.50	2,528			1,966.50	0.24 (0.04–0.39)	0.08 (0.00–0.22)	0.69 (0.58–0.81)
CE	7,032.10	2,531	9.60	0.02	3.60	–	0.22 (0.14–0.30)	0.78 (0.70–0.86)
AE	7,030.02	2,531	7.52	0.06	1.52	0.33 (0.22–0.43)	–	0.67 (0.57–0.78)
						Low self-control II		
ACE	6,890.35	2,535			1,820.35	0.26 (0.04–0.40)	0.06 (0.00–0.22)	0.68 (0.57–0.80)
CE	6,899.01	2,538	8.66	0.03	2.66	–	0.22 (0.14–0.30)	0.78 (0.70–0.86)
AE	6,896.29	2,538	5.94	0.12	−0.06	0.33 (0.22–0.43)	–	0.67 (0.57–0.78)
						Low self-control II		
ACE	5,781.85	2,532			717.85	0.27 (0.08–0.41)	0.06 (0.00–0.19)	0.68 (0.57–0.79)
CE	5,790.72	2,535	8.87	0.03	2.87	–	0.22 (0.14–0.30)	0.78 (0.70–0.86)
AE	5,787.27	2,535	5.43	0.14	−0.57	0.33 (0.22–0.44)	–	0.67 (0.56–0.78)

Model fit		Variable 2			*r*		
	−2lnl	*A*	*C*	*E*	*g*	*c*	*e*
		Overall delinquency II					
ACE	7,022.50	0.13 (0.00–0.38)	0.28 (0.08–0.42)	0.60 (0.50–0.70)	−0.06 (−1–1)	1 (0.33–1)	0.33 (0.21–0.44)
CE	7,032.10	–	0.36 (0.29–0.43)	0.64 (0.57–0.71)	–	0.51 (0.32–0.70)	0.29 (0.21–0.36)
AE	7,030.02	0.46 (0.37–0.53)	–	0.54 (0.47–0.63)	0.43 (0.24–0.60)	–	0.30 (0.19–0.41)
		Nonviolent delinquency II					
ACE	6,890.35	0.14 (0.00–0.40)	0.25 (0.05–0.40)	0.61 (0.51–0.72)	0.13 (−1–1)	1 (−1–1)	0.27 (0.15–0.38)
CE	6,899.01	–	0.34 (0.27–0.41)	0.66 (0.59–0.73)	–	0.53 (0.33–0.72)	0.25 (0.17–0.33)
AE	6,896.29	0.44 (0.35–0.52)	–	0.56 (0.48–0.65)	0.46 (0.28–0.64)	–	0.24 (0.13–0.34)

Table 4 continued

Model fit		Variable 2			r		
	−2lnl	*A*	*C*	*E*	*g*	*c*	*e*
		Violent delinquency II					
ACE	5,781.85	0.01 (0.00–0.27)	0.23 (0.04–0.31)	0.76 (0.65–0.84)	−1.00 (−1–1)	1 (−0.22–1)	0.27 (0.16–0.37)
CE	5,790.72	–	0.24 (0.16–0.31)	0.76 (0.69–0.84)	–	0.36 (0.09–0.60)	0.22 (0.14–0.30)
AE	5,787.27	0.30 (0.20–0.39)	–	0.70 (0.61–0.80)	0.26 (−0.01–0.49)	–	0.25 (0.14–0.35)

Note: 95% confidence interval not including 0 indicates a significant parameter at $p < 0.05$

measures of delinquency at wave II is due to common genetic factors with the remaining 45–68% attributed to common nonshared environmental factors (Table 2).

At wave III, the correlations between low self-control and offending are all statistically significant (Table 2). Table 5 reveals that the proportion of the variance in low self-control at wave III accounted for by genetic factors is 44% and by nonshared environmental factors is 56%. For overall, nonviolent, and violent delinquency at wave III, the proportion of the variance accounted for by genetic effects is 39, 35, and 31% and by nonshared environmental effects is 61, 65, and 69%, respectively. Further calculations revealed that between 62 and 67% of the correlation found between low self-control and measures of offending at wave III was due to common genetic factors while the remaining 33–38% was due to common nonshared environmental factors (Table 2).[11]

Discussion

Gottfredson and Hirschi's (1990) theory focuses primarily on the environmental factors that influence levels of low self-control and criminal behaviors while overlooking the important genetic effects on these two types of behaviors. Specifically, Gottfredson and Hirschi (1990) assert that effective parental socialization techniques, such as monitoring and discipline, are needed in order to instill self-control in a child. They further argue that the magnitude of the genetic effect on delinquent behaviors is near zero. The results from the current study call into question these two claims by demonstrating that *both* genetic and environmental factors are important when examining levels of low self-control and delinquency in a sample of adolescents and young adults.

First, the analyses revealed that the measure of low self-control was moderately influenced by genetic factors across all three time periods, with heritability estimates ranging between 0.33 and 0.45. Although falling within the lower range, these results align with previous criminological studies that have found that 40–72% of the variance in low self-control was attributed to genetic influences (Beaver et al. 2008a, d, 2009c; Wright et al. 2008). These results also add to the growing number of behavioral genetic studies that have estimated the genetic and environmental contributions to constructs related to low self-control, such as hyperactivity (Silberg et al. 1996; Thapar et al. 1995), impulsivity (Kuntsi et al. 2000), attention problems (Edelbrock et al. 1995; Gjone et al. 1996), overactivity (Rietveld et al. 2003, 2004), ADHD (Eaves et al. 1997; Gilger et al. 1992; Knopik et al. 2005; Sherman et al. 1997; Spencer et al. 2002), sensation seeking (Fulker et al. 1980; Hur and Bouchard 1997; Koopmans et al. 1995), and other self-regulatory problems (Young et al. 2000; Zahn-Waxler et al. 1996).

Overall, these studies have found heritability estimates for constructs related to Gottfredson and Hirschi's concept of low self-control that ranged between 0.65 and 0.85. Taken together, our results add to the body of literature that calls into question Gottfredson and Hirschi's claim that environmental factors, primarily parenting practices, are solely

[11] We also conducted our analyses using an expanded measure of self-control developed by Beaver et al. (2009a, b). The results from those additional analyses virtually mirrored those presented here and are available upon request. Specifically, across the three waves, genetic factors accounted for 40–45, 38–56, 35–51, 30–56% of the variance in self-control, overall delinquency, nonviolent delinquency, and violent delinquency, respectively. Furthermore, the estimates showed that, across the three waves, common genetic factors accounted for 45–80, 46–79, and 26–75% of the covariance between low self-control and overall delinquency, between low self-control and nonviolent delinquency, and between low self-control and violent delinquency, respectively.

Table 5 Bivariate analyses of low self-control and offending at wave III (parameter estimates and 95% confidence interval)

Model fit		Change statistics				Variable 1		
	−2lnl	*df*	ΔX^2	*P*	AIC	*A*	*C*	*E*
						Low self-control III		
ACE	7,263.25	2,292			2,679.25	0.44 (0.29–0.54)	0.00 (0.00–0.10)	0.56 (0.46–0.66)
CE	7,284.02	2,295	20.77	0.00	14.77	–	0.28 (0.19–0.36)	0.72 (0.64–0.81)
AE	7,263.25	2,295	0.00	1.00	−6.00	0.44 (0.34–0.54)	–	0.56 (0.46–0.66)
						Low self-control III		
ACE	6,985.77	2,306			2,373.77	0.44 (0.29–0.54)	0.00 (0.00–0.11)	0.56 (0.46–0.66)
CE	7,010.28	2,309	24.51	0.00	18.51	–	0.28 (0.19–0.36)	0.72 (0.64–0.81)
AE	6,985.77	2,309	0.00	1.00	−6.00	0.44 (0.34–0.54)	–	0.56 (0.46–0.66)
						Low self-control III		
ACE	5,993.39	2,297			1,399.39	0.43 (0.25–0.54)	0.02 (0.00–0.14)	0.56 (0.46–0.67)
CE	6,011.12	2,300	17.73	0.00	11.73	–	0.28 (0.19–0.36)	0.72 (0.64–0.81)
AE	5,994.86	2,300	1.47	0.69	−4.53	0.44 (0.34–0.54)	–	0.56 (0.46–0.66)

Model fit		Variable 2			*r*		
	−2lnl	*A*	*C*	*E*	*g*	*c*	*e*
		Overall offending III					
ACE	7,263.25	0.39 (0.07–0.49)	0.00 (0.00–0.23)	0.61 (0.51–0.74)	0.48 (0.20–1)	1 (−1–1)	0.17 (0.05–0.29)
CE	7,284.02	–	0.25 (0.17–0.33)	0.75 (0.67–0.83)	–	0.44 (0.22–0.66)	0.24 (0.16–0.33)
AE	7,263.25	0.39 (0.28–0.49)	–	0.61 (0.51–0.72)	0.48 (0.30–0.65)	–	0.17 (0.05–0.29)
		Nonviolent offending III					
ACE	6,985.77	0.35 (0.16–0.45)	0.00 (0.00–0.13)	0.65 (0.55–0.76)	0.41 (0.13–0.66)	0.97 (−0.76–1)	0.14 (0.01–0.25)
CE	7,010.28	–	0.22 (0.13–0.30)	0.78 (0.70–0.87)	–	0.41 (0.16–0.66)	0.18 (0.10–0.27)
AE	6,985.77	0.35 (0.24–0.45)	–	0.65 (0.55–0.76)	0.41 (0.20–0.60)	–	0.14 (0.01–0.25)

Table 5 continued

Model fit		Variable 2			r		
	−2lnl	*A*	*C*	*E*	*g*	*c*	*e*
		Violent offending III					
ACE	5,993.39	0.17 (0.01–0.40)	0.10 (0.00–0.23)	0.73 (0.59–0.85)	0.79 (0.23–1)	−1 (−1–1)	0.15 (0.02–0.28)
CE	6,011.12	–	0.19 (0.11–0.27)	0.81 (0.73–0.89)	–	0.29 (0.01–0.54)	0.25 (0.17–0.33)
AE	5,994.86	0.31 (0.19–0.43)	–	0.69 (0.57–0.81)	0.43 (0.21–0.63)	–	0.17 (0.04–0.29)

Note: 95% confidence interval not including 0 indicates a significant parameter at $p < 0.05$

responsible for levels of self-control. Clearly, the effects of genetic factors on low self-control should be taken into account in future studies otherwise Gottfredson and Hirschi's theory is at risk of being misspecified (Wright and Beaver 2005).

Second, Gottfredson and Hirschi (1990) explicitly deny the effects that genetic factors play in explaining variation in delinquency. However, there are hundreds of studies that have shown that genetic influences are important factors to consider when discussing variation in antisocial behaviors (see Moffitt 2005). Our results are aligned with these studies by demonstrating that, across the three waves, genetic effects account for 39–58, 35–53, and 30–53% of the variance in overall delinquency, nonviolent delinquency, and violent delinquency, respectively. The remaining variance in all three measures of delinquency was accounted for by nonshared environmental factors while the effects of shared environmental influences were negligible.[12] Therefore, it appears as though Gottfredson and Hirschi (1990) are fundamentally incorrect when they state that the effect of genetic factors on delinquent behaviors is insignificant.

Of the hundreds of studies that have examined the heritability of antisocial behaviors, many have disaggregated delinquency into violent and nonviolent forms of antisocial behaviors. A recent meta-analysis by Burt (2009) has shown that, across the studies, genetic effects appear to be stronger in aggressive forms of antisocial behaviors compared to nonaggressive forms of antisocial behaviors and that shared environmental factors are more pronounced in nonaggressive forms of antisocial behaviors. The results from the current analyses, however, suggest that there is no significant difference in the heritability estimates between violent and nonviolent types of delinquency. Similar null findings have been reported elsewhere (Button et al. 2004; Gelhorn et al. 2005). We suggest that future research consider disaggregating the items included in the nonviolent and violent delinquency/offending scales. As Gelhorn et al. (2005) argue, certain items may be more or less heritable than others. Thus, a more thorough examination of the individual non-violent items (e.g., stealing, selling drugs, damaging property) and violent offending (e.g., physical fighting, shooting/stabbing, hurting someone) may show significant differences in genetic and environmental effects across particular items.

Overall, the results presented in this study, along with many others, suggest that both low self-control and delinquency are influenced by genetic factors. Furthermore, several studies have revealed a strong relationship between low self-control and various forms of delinquent/antisocial behaviors (Arneklev et al. 1993; Burton et al. 1998; DeLisi 2001; Gibbs et al. 2003; Grasmick et al. 1993; Keane et al. 1993; Longshore and Turner 1998; Piquero and Tibbetts 1996; Vazsonyi and Crosswhite 2004). The current study adds to this literature by revealing a significant correlation, across the three waves, between low self-control and overall delinquency (i.e., 0.30–0.36), low self-control and nonviolent delinquency (i.e., 0.24–0.34), and low self-control and violent delinquency (i.e., 0.25–0.26). These effect sizes are similar to those reported in Pratt and Cullen's (2000) meta-analysis.

The observed correlation found between low self-control and offending was also partitioned into its genetic and environmental components. Our findings revealed that common genetic and nonshared environmental factors were partially responsible for the co-occurrence of low self-control and delinquent behaviors across three time periods. Specifically, the estimates showed that, across the three waves, common genetic factors accounted for 49–83%, 55–82%, and 32–83% of the covariance between low self-control

[12] Our results differ slightly from the meta-analyses by Rhee and Waldman (2002) and Burt (2009) who reported that shared environmental influences account for 16 and 18% of the variance in antisocial behaviors and nonaggressive forms of antisocial behaviors, respectively.

and overall delinquency, between low self-control and nonviolent delinquency, and between low self-control and violent delinquency, respectively. These estimates are aligned with others that have also shown that common genetic factors are partially responsible for the co-occurrence of constructs related to Gottfredson and Hirschi's concept of low self-control and various forms of antisocial behaviors. Specifically, previously reported studies have shown moderate to strong genetic correlations between hyperactivity-impulsivity and aggression (Vierikko et al. 2004), hyperactivity and oppositional-defiant disorder/conduct disorder (Silberg et al. 1996), ADHD and oppositional-defiant disorder/conduct disorder (Burt et al. 2001; Nadder et al. 1998, 2002; Young et al. 2000), as well as attention problems and aggression (Schmitz and Mrazek 2001).

Future Research

Our results provide an overall estimate of the genetic and environmental contributions to low self-control and offending as well as to their relationship with one another. However, the results do not provide any information on the *specific* genes or environmental factors that are simultaneously influencing both behaviors. Many studies have examined the role that genetic polymorphisms play in explaining variation in levels of impulsivity and antisocial behaviors. For example, it has been suggested that polymorphisms in genes related to the dopamine system (DAT1, DRD2, DRD4) and in the MAOA[13] promoter gene are associated with both lower levels of self-control (Arcos-Burgos et al. 2004; Becker et al. 2005; El-Faddagh et al. 2004; Laucht et al. 2005; Manor et al. 2002; Manuk et al. 2000; Mill et al. 2005; Qiujin et al. 2004) and various forms of antisocial/criminal behaviors (Beitchman et al. 2004; Manuk et al. 2000; Ponce et al. 2003; Schmidt et al. 2000; Young et al. 2002). However, not all studies have replicated these findings (Comings et al. 2000a, b; Frank et al. 2004; Kirley et al. 2004; Koller et al. 2003; Kotler et al. 2000; Lawson et al. 2003; Lee et al. 2003; Lu et al. 2003; Mill et al. 2005; Simsek et al. 2005; Smith et al. 2003; Tsai et al. 2004). These inconsistencies in the literature highlight the need for continued association and linkage studies aimed at pinpointing the specific genes that are influencing both low self-control and antisocial/criminal behaviors.

In terms of environmental factors, it is clear that the nonshared environmental factors are exerting a substantial effect on both low self-control and delinquency. Specifically, our results revealed that dropping the effects of shared environmental factors did not significantly reduce the fit of any of the bivariate genetic models. This suggests that shared environmental factors have a minimal impact on low self-control and delinquency. These results are aligned with other behavioral genetic studies on low self-control (Beaver et al. 2008a, d, 2009c; Wright et al. 2008) and antisocial behaviors (Arseneault et al. 2003; Dionne et al. 2003; Goldstein et al. 2001; Hicks et al. 2004; Hudziak et al. 2000; Krueger et al. 2001; Miles et al. 2002) that have also shown that shared environmental effects are negligible.[14]

It appears as though it is the unique experiences by the individual child that are most influential in explaining variation in behaviors. As Plomin (1990) states, it is the small

[13] MAOA is an enzyme that breaks down neurotransmitters, such as dopamine, serotonin, and epinephrine.

[14] However, it is possible that the effects of shared environment were underestimated due to the lack of inclusion of other siblings of varying degrees of genetic relatedness. Using an extended-twin design could potentially increase the statistical power to detect shared environmental influences (Posthuma and Boomsma 2000). Also, our results differ slightly from the meta-analysis by Rhee and Waldman (2002) which revealed that 41, 16, and 43% of the variance in antisocial behaviors is attributed to genetic, shared, and nonshared environmental factors, respectively.

differences in experiences that can lead to large differences in child development. For example, research has shown that parents tend to treat their children differently (Brody and Stoneman 1994; Brody et al. 1987; Daniels et al. 1985; McHale and Pawletko 1992; Stocker 1993, 1995) and that these differences in parental treatment, in turn, have an effect on behavioral problems in siblings, such as internalizing and externalizing behaviors (Boisvert and Wright 2008; Dunn et al. 1990; McGuire et al. 1995) and delinquency (Conger and Conger 1994). Future research should continue to isolate the nonshared environmental influences occurring both within and outside the home in order to better understand and decipher these important factors.

Another potential avenue for future research in studying the relationship between self-control and antisocial behaviors is the brain, particularly the frontal lobe. The frontal lobe is the anterior portion of the brain that is responsible for various executive functions, including abstract thinking, problem-solving, and self-control. Several studies have shown that dysfunction in the prefrontal lobe is associated with both lower levels of self-control and higher levels of antisocial behaviors. These results suggest that prevention and intervention efforts should target brain functioning through neuropsychological training exercises (DeLisi and Vaughn 2011; Ross and Hilborn 2008; Vaske et al. 2011). Current prevention/intervention programs that include some of these elements are Reasoning and Rehabilitation 2 (R&R2), Tools of the Mind, and Promoting Alternative Thinking Strategies (PATHS). Evaluations of these programs have demonstrated that they are effective at improving neuropsychological skills, improving self-control, and decreasing antisocial behaviors (Diamond et al. 2007; Greenberg et al. 2006; Young et al. 2010).

Limitations

There are at least four limitations to the current study that need to be addressed. The first issue pertains to the generalizability of the results reported in this study. Although the use of a twin subsample was essential to conduct the genetic analyses in this study, the generalizability of our results to the population remains an issue. This is primarily due to the similar prenatal and perinatal experiences of twins compared to singletons (see Rutter et al. 1993). Specifically, twins are more likely to experience birth complications and lower birth weights (Moilanen and Ebeling 1998), which in turn have been associated with both low self-control and delinquency (Beaver and Wright 2005; Tibbetts and Piquero 1999). The second limitation involves the use of self-reported measures of low self-control and delinquency. The reliability of self-reported data is especially questionable when items, such as a participant's level of delinquent involvement, are sensitive in nature. Although Add Health employed the Audio Computer Assisted Self-Interviewing (ACASI) technique to increase the chances of truthful responses by participants, it is recommended that future studies include multiple raters and/or information sources (Bartels et al. 2003; van der Ende and Verhulst 2005). Third, we recommend replicating these analyses using different data sets with more direct measures of self-control, such as the Grasmick scale (Grasmick et al. 1993). The final limitation is in regards to the small number of twin pairs included in the Add Health data relative to other twin registries, such as the *FinnTwin12* and the Minnesota Twin Family Study. As evident from the confidence intervals reported in this study, a greater number of twin pairs would be ideal for future studies intending to replicate the analyses included in this study. It is possible that the effects of the shared environment were not detected as the results of the small sample size (Martin et al. 1978). Also, a greater number of twin pairs may have allowed for additional analyses to examine whether these findings are the same for males and females. However, due to the low prevalence of offending, particularly violent offending, in the number of same-sex female twin pairs ($N = 250$), sex limitation models were not performed but are encouraged in future research.

In conclusion, the exclusion of genetic and biological factors is a reoccurring issue in traditional criminological research. Criminological theories, such as Gottfredson and Hirschi's general theory of crime, could be greatly advanced by integrating knowledge from the biological sciences (Walsh 2002; Wright and Beaver 2005). There is little doubt that low self-control is an important correlate of delinquent and analogous behaviors. What remains to be acknowledged, however, are the underlying genetic and biological contributions to both self-control and delinquency. The results from the current study highlight the importance of considering the potential genetic and nonshared environmental factors that are simultaneously operating on low self-control and delinquency to help explain the consistent relationship found between these two phenotypes.

Appendix

Low Self-Control at Wave I

1. How often do you have trouble getting along with your teachers[a]
2. How often do you have trouble paying attention in school[a]
3. How often do you have trouble getting your homework done [a]
4. How often do you have trouble getting along with other students[a]
5. How often did you have trouble keeping your mind on what you were doing, during the past seven days[b]

Response Categories: [a]0 = never, 1 = just a few times, 2 = about once a week, 3 = almost everyday, 4 = everyday. [b]0 = never or rarely, 1 = sometimes, 2 = a lot of the time, 3 = most of the time or all of the time. ($\alpha = 0.71$)

Low Self-Control at Wave II

1. How often do you have trouble getting along with your teachers[a]
2. How often do you have trouble paying attention in school[a]
3. How often do you have trouble getting your homework done[a]
4. How often do you have trouble getting along with other students[a]
5. How often did you have trouble keeping your mind on what you were doing, during the past seven days[b]

Response Categories: [a]0 = never, 1 = just a few times, 2 = about once a week, 3 = almost everyday, 4 = everyday. [b]0 = never or rarely, 1 = sometimes, 2 = a lot of the time, 3 = most of the time or all of the time. ($\alpha = 0.67$)

Low Self-Control at Wave III

1. I often try new things just for fun or thrills, even if most people think they are a waste of time
2. When nothing new is happening, I usually start looking for something exciting
3. I often do things based on how I feel at the moment
4. I sometimes get so excited that I lose control of myself

5. I like it when people can do whatever they want, without strict rules and regulations
6. I often follow my instincts, without thinking through all the details
7. I change my interest a lot, because my attention often shifts to something else

Response Categories: 0 = not true, 1 = a little true, 2 = somewhat true, 3 = pretty true, 4 = very true. ($\alpha = 0.84$)

Overall Delinquency at Wave I and II

In the past 12 months, how often did you:

1. Get into a serious physical fight[a]
2. Hurt someone badly enough to need bandages or care from a doctor or nurse[a]
3. Use or threaten to use a weapon to get something from someone[a]
4. Take part in a fight where a group of your friends were against another group[a]
5. Pull a knife or a gun on someone[b]
6. You shot or stabbed someone[b]
7. Paint graffiti or signs on someone else's property or in a public place[a]
8. Deliberately damage property that didn't belong to you[a]
9. Take something from a store without paying for it[a]
10. Drive a car without its owner's permission[a]
11. Steal something worth more than $50[a]
12. Go into a house or building to steal something[a]
13. Sell marijuana or other drugs[a]
14. Steal something worth less than $50[a]

Response Categories: [a]0 = never, 1 = one or two times, 2 = three or four times, 3 = five or more times. [b]0 = never, 1 = once, 2 = more than once. (wave I $\alpha = 0.84$; wave II $\alpha = 0.81$)

Overall Offending at Wave III

1. Use a weapon in a fight[a]
2. Hurt someone badly enough to need bandages or care from a doctor or nurse[a]
3. Use or threaten to use a weapon to get something from someone[a]
4. Take part in a fight where a group of your friends were against another group[a]
5. Pull a knife or a gun on someone[b]
6. You shot or stabbed someone[b]
7. Deliberately damage property that didn't belong to you[a]
8. Steal something worth more than $50[a]
9. Go into a house or building to steal something[a]
10. Sell marijuana or other drugs[a]
11. Steal something worth less than $50[a]
12. Buy, sell, or hold stolen property[a]
13. Use someone else's credit or bank card without their permission or knowledge[a]
14. Deliberately write a bad check[a]

Response Categories: [a]0 = never, 1 = one or two times, 2 = three or four times, 3 = five or more times. [b]0 = no, 1 = yes. ($\alpha = 0.73$)

Violent Delinquency at Waves I and II

In the past 12 months, how often did you:

1. Get into a serious physical fight[a]
2. Hurt someone badly enough to need bandages or care from a doctor or nurse[a]
3. Use or threaten to use a weapon to get something from someone[a]
4. Take part in a fight where a group of your friends were against another group[a]
5. Pull a knife or a gun on someone[b]
6. You shot or stabbed someone[b]

Response Categories: [a]0 = never, 1 = one or two times, 2 = three or four times, 3 = five or more times. [b]0 = never, 1 = once, 2 = more than once. (wave I $\alpha = 0.75$; wave II $\alpha = 0.72$)

Violent Offending at Wave III

In the past 12 months, how often did you:

1. Use a weapon in a fight[a]
2. Hurt someone badly enough to need bandages or care from a doctor or nurse[a]
3. Use or threaten to use a weapon to get something from someone[a]
4. Take part in a fight where a group of your friends were against another group[a]
5. Pull a knife or a gun on someone[b]
6. You shot or stabbed someone[b]

Response Categories: [a]0 = never, 1 = one or two times, 2 = three or four times, 3 = five or more times. [b]0 = no, 1 = yes. ($\alpha = 0.52$)

Non-Violent Delinquency at Waves I and II

In the past 12 months, how often did you:

1. Paint graffiti or signs on someone else's property or in a public place
2. Deliberately damage property that didn't belong to you
3. Take something from a store without paying for it
4. Drive a car without its owner's permission
5. Steal something worth more than $50
6. Go into a house or building to steal something
7. Sell marijuana or other drugs
8. Steal something worth less than $50

Response Categories: 0 = never, 1 = one or two times, 2 = three or four times, 3 = five or more times. (wave I $\alpha = 0.78$; wave II = 0.77)

Non-Violent Offending at Wave III

In the past 12 months, how often did you:

1. Deliberately damage property that didn't belong to you
2. Steal something worth more than $50
3. Go into a house or building to steal something

4. Sell marijuana or other drugs
5. Steal something worth less than $50
6. Buy, sell, or hold stolen property
7. Use someone else's credit or bank card without their permission or knowledge
8. Deliberately write a bad check

Response Categories: 0 = never, 1 = one or two times, 2 = three or four times, 3 = five or more times. ($\alpha = 0.66$)

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