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Social Support an the Impact of Head Injuries on Delinquency in an Urban Sample of Adjudicated Youth: Applications for the Douglas County Department of Corrections

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Douglas County Corrections

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University of Nebraska Omaha

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An evaluation of the directional relationship between head injuries and subsequent changes in impulse control and delinquency in a sample of previously adjudicated males[☆]

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ABSTRACT

Research over the past decade has found that head injuries are associated with negative outcomes including lower levels of self-control and a greater prevalence of delinquent behavior. Despite this pattern of findings, previous research remains unclear as to whether head injuries influence subsequent levels of self-control and delinquency, or whether lower levels of self-control increase the likelihood of sustaining a head injury. The current study begins to address this gap in the literature by analyzing longitudinal data spanning from childhood to young adulthood on adolescent offenders from the Pathways to Desistance study. A series of cross-lagged autoregressive path models were estimated to examine the prospective associations between head injuries, changes in impulse control (a dimension of self-control), and delinquency while controlling for stability in all three constructs. Findings indicate: 1) impulse control and delinquency displayed significant levels of stability across the study period; 2) head injuries appear to occur prior to decreases in impulse control; 3) decreases in impulse control do not appear to systematically increase the odds of sustaining future head injuries; and 4) head injuries did not appear to result in systematic increases in delinquent behavior across the life course.

1. Introduction

There are few theoretical perspectives within the field of criminology that have received as much attention as Gottfredson and Hirschi's (1990) self-control theory. What is perhaps even more surprising than the overall volume of research focused on self-control theory is that the number of studies published examining various aspects of this theoretical perspective has continued to grow year after year (Vazsonyi, Mikuška, & Kelley, 2017). There are multiple explanations for criminology's continued interest in self-control theory, but perhaps the most convincing explanation is directly centered on the association between self-control and criminal behavior (or other forms of deviance). Findings from the extensive body of literature examining the association between self-control and antisocial behaviors are remarkably consistent, with findings showing that lower overall levels of self-control are significantly associated with various forms of antisocial behavior (de Ridder, Lensvelt-Mulders, Finkenauer, Stok, & Baumeister, 2012; Pratt & Cullen, 2000; Vazsonyi et al., 2017). Based on these findings, it comes as little surprise that self-control theory has quickly become a mainstay of criminological research.

The proliferation of research examining various aspects of self-control theory has also resulted in a well-developed body of literature examining the etiological development of self-control across the life-course. Collectively, findings from this line of research have identified a relatively broad range of factors that ultimately contribute to individual variability in self-control. Factors involved in creating differences in self-control include a sizable number of both environmental (Burt, Simons, & Simons, 2006; Gibson, Sullivan, Jones, & Piquero, 2010) and biological (Beaver, Wright, & DeLisi, 2007; Cauffman, Steinberg, & Piquero, 2005; DeLisi, 2014) influences. Directly in line

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with these findings, preliminary evidence from research outside of criminology points to head injuries as a potential environmental experience that may influence changes in neurobiological structure and function to produce variability in self-control (Steinberg, 2008). Despite this preliminary evidence suggesting that head injuries may serve as a substantive source of influence on the development of self-control, these findings are tempered by important methodological limitations. Most importantly, previous research is typically confined to a limited number of observation periods, resulting in potential selection bias whereby individuals with lower overall levels of self-control may simply be more likely to find themselves in situations where head injuries are more likely to occur (e.g., physical fights, car accidents). The current study aims to begin to address this limitation in the existing body of literature by examining the association between head injuries, delinquency, and a specific dimension of self-control—impulse control—in a sample of previously adjudicated youth from the Pathways to Desistance (Pathways) study (Mulvey et al., 2004). The Pathways study offers the unique advantage of a panel design with repeated observations that span a total of eight years of the life course—spanning from adolescence to early adulthood. This repeated panel design, along with the employed analytic strategy, allows for a more detailed examination of the longitudinal associations between head injuries, delinquency, and impulse control, by attempting to better establish temporal order and minimize selection bias.

2. The evolution of self-control in criminological research

The results of three separate systematic reviews of the literature have demonstrated the importance of self-control in the etiological development of antisocial behavior (de Ridder et al., 2012; Pratt & Cullen, 2000; Vazsonyi et al., 2017). In the now classic meta-analysis performed by Pratt and Cullen (2000), the authors examined studies from the decade following the publication of Gottfredson and Hirschi's (1990) book. The results of 21 studies and over 49,000 individual cases indicated that "low self-control consistently had an effect size that exceeded 0.20" (p. 951). Importantly, the observed effect size was robust to a wide range of potentially moderating influences including differences in measurement, sample characteristics, and the type of antisocial behavior examined. A more recent meta-analysis by de Ridder et al. (2012) examined the existing body of literature focused on self-control and antisocial behavior as well as a broad range of other potential outcomes (e.g., school success, well-being). The results revealed a pattern that closely aligned with findings presented by Pratt and Cullen (2000), with mean correlations for self-control and antisocial behavior ranging from 0.15 to 0.25. Finally, the most recent meta-analysis examining the self-control-antisocial behavior association was performed by Vazsonyi et al. (2017) and focused on research published in the decade following Pratt and Cullen's study (between 2000 and 2010). Once again, the overall pattern of results largely converged with both previous meta-analyses and revealed moderately sized effects for both cross-sectional ($r = 0.42$) and longitudinal ($r = 0.35$) studies. Collectively, the results of these systematic reviews reveal a robust and sizable association between low self-control and various forms of antisocial behavior, effectively demonstrating the importance of self-control in future research examining the etiological development of antisocial behavior.

Based, at least in part, on these findings, studies have begun to examine other aspects of self-control theory, with studies beginning to focus on factors that ultimately contribute to variability in overall levels of self-control (Burt et al., 2006; Franken et al., 2016; Teasdale & Silver, 2009). While Gottfredson and Hirschi (1990) pointed to one specific source of influence (i.e., parental socialization) and provided a straightforward explanation of how these factors may be involved in creating differences in self-control, subsequent research has demonstrated that influences which ultimately culminate into variability in self-control are likely far more complex (Pratt, Turner, & Piquero, 2004). For example, while studies have demonstrated an overwhelming amount of support for Gottfredson and Hirschi's parental socialization thesis (Hay & Forrest, 2006; Pratt et al., 2004), additional research has also demonstrated that the parent-child interactions involved in the development of self-control are far more intricate (Brauer, 2016; Hay, 2001). In addition, a large, and continually developing, body of research has pointed to additional sources of influence that ultimately contribute to the development of self-control including peer interactions (Franken et al., 2016; Gardner & Steinberg, 2005; Meldrum & Hay, 2012; Meldrum, Young, & Weerman, 2012), school-based influences (Burt et al., 2006; Turner, Piquero, & Pratt, 2005), neighborhood characteristics (Gibson et al., 2010; Pratt et al., 2004; Teasdale & Silver, 2009), and even targeted interventions (for a recent systematic review see Piquero, Jennings, Farrington, Diamond, & Gonzalez, 2016). These findings have encouraged criminologists to explore a wider range of influences that contribute to the long-term development self-control across various stages of the life-course.

In addition to the proliferation of studies exploring additional social influences on the development of self-control, a related line of research focused on the biological factors involved in the development of self-control has also emerged (Beaver et al., 2009; Cauffman et al., 2005; Harden, Quinn, & Tucker-Drob, 2012). Drawing from studies demonstrating an intergenerational transmission of self-control from parents to offspring (Boutwell & Beaver, 2010; Meldrum, Verhoeven, Junger, van Aken, & Deković, 2016; Meldrum, Young, & Lehmann, 2015; Nofziger, 2008), additional research has focused on identifying relevant genetic and neurobiological influences (Beaver, Connolly, Schwartz, Al-Ghamdi, & Kobeisy, 2013; Connolly & Beaver, 2014; Schwartz, Rowland, & Beaver, 2014; Steinberg, 2008; Wright & Beaver, 2005) involved in creating individual differences in self-control. Findings from this line of research suggest that self-control is a brain-based construct, shaped by a complex combination of biological and environmental influences (Beaver et al., 2007; Beaver et al., 2009; Cauffman et al., 2005; DeLisi, 2014).

Most of the research in this area conceptualizes self-control as an *executive function*, which has been previously described as "a wide range of cognitive processes and behavioral competencies which include verbal reasoning, problem-solving, planning, sequencing, the ability to sustain attention, resistance to interference, utilization of feedback, multitasking, cognitive flexibility, and the ability to deal with novelty" (Chan, Shum, Toulopoulou, & Chen, 2008, p. 201). Importantly, results from two recent meta-analyses have linked executive functions to the structure and functioning of specific regions of the frontal lobes, including components of the prefrontal cortex (Alvarez & Emory, 2006; Yuan & Raz, 2014). First, Yuan and Raz (2014) performed a systematic review of studies examining structural aspects of the prefrontal cortex and executive functions. The results from 31 studies and over 3000 participants indicated that increased volume ($d = 0.31$) and cortical thickness ($d = 0.19$) in the prefrontal cortex was significantly associated with better executive function. Second, Alvarez and Emory (2006) performed a systematic review of the literature examining differences in executive functions between individuals who had sustained lesions to the frontal lobes and healthy controls. The results revealed stark differences between the two groups, with individuals who suffered damage to their frontal lobes performing significantly worse on measures of executive functions relative to their counterparts ($d = -0.78$). These findings suggest that: (1) self-control, and other executive functions, are tied to structural and functional characteristics of the frontal lobes (and, more specifically, the prefrontal cortex); and (2) damage to these specific regions of the brain may result in impaired executive function.

3. Head injuries and self-control

Directly in line with these findings, it stands to reason that sustaining a head injury may result in damage to the frontal lobes, which may ultimately lead to lower overall levels of self-control. Head injuries represent an ideal environmental candidate, as previous studies have found that such injuries are significantly associated with subsequent neurocognitive processes, including cognitive ability, attention, working memory, language fluidity, information processing speed, and even reductions in executive functioning (Dikmen et al., 2009; Polito, Thompson, & DeFina, 2010; Rohling, Faust, Beverly, & Demakis, 2009). In addition, previous studies have revealed that head injuries are disproportionally experienced by incarcerated populations, with some estimates indicating that the risk of such an injury is 10 times greater within an incarcerated population compared to individuals from the general population (Barnfield & Leathem, 1998; Behnken, DeLisi, Trulson, & Vaughn, 2015; DelBello et al., 1999; Farrer & Hedges, 2011; Langevin, 2006; Perron, Vaughn, Ryan, Salas-Wright, & Guerrero, 2015; Shiroma, Ferguson, & Pickelsimer, 2010). Similarly, the results of a recent study by Ray and Richardson (2017) examining a sample of inmates from Indiana found that those inmates who had previously sustained a traumatic brain injury were nearly twice as likely to recidivate during the study period (between 12 and 29 months following release), compared to their non-injured counterparts.

Despite findings from previous research indicating that individuals who sustain a serious head injury are significantly more likely to experience other problems also related to antisocial behavior such as aggression and anger (Fishbein, Dariotis, Ferguson, & Pickelsimer, 2016; Grafman et al., 1996; Kim, Manes, Kosier, Baruah, & Robinson, 1999; Rao et al., 2009; Tateno, Jorge, & Robinson, 2003), the existing literature suffers from several limitations that make the resulting associations difficult to interpret. Perhaps the most concerning limitation surrounds the possibility of selection that differentially predisposes a specific subset of individuals to a head injury. Due to lifestyle choices that accompany increased levels of delinquency or lower overall levels of self-control, some individuals may simply be more likely than others to sustain a head injury at the outset. This possibility is further underscored by Pratt's (2016) recent extension of self-control theory, which effectively nests classic self-control theory within a developmental framework. More specifically, Pratt argues that overall levels of self-control not only influence selection into negative life events, but also directly impact the coping strategies employed after sustaining such events. Within the context of the current study, this observation would seem to indicate that individuals with lower overall levels of self-control may be more likely to not only sustain a head injury, but would also be less likely to seek appropriate interventions afterward. This observation presents a methodological concern, as a sizable portion of the existing research examining the potential association between head injuries and antisocial behavior is largely descriptive (i.e., comparing the prevalence of head injuries between incarcerated and non-incarcerated populations; e.g., Farrer & Hedges, 2011; Perron et al., 2015; Shiroma et al., 2010), raising concerns surrounding selection and effectively establishing temporal order.

Even in situations where a multivariate framework is employed, most studies are still unable to determine whether deleterious outcomes occurred before or after a head injury (e.g., Behnken et al., 2015; Ray & Richardson, 2017). For example, Schwartz, Connolly, and Brauer (2017) recently examined a sample of adjudicated youth from the Pathways study and found that youth with head injuries reported lower overall levels of self-control and higher levels of aggressive delinquency in adolescence. Results from longitudinal analyses revealed that self-control during adolescence operated as a significant mediator between self-reported head injuries and rates of change in aggressive delinquency from adolescence to early adulthood. While these findings align with findings from other studies (e.g., Fishbein et al., 2016) to provide preliminary evidence suggesting that head injuries may result in increased levels of delinquency through changes in self-control, the employed analytic approach (i.e., latent growth curve models) cannot effectively ensure that the examined head injuries occurred prior to changes in self-control and delinquency. Taken together, these findings provide evidence suggesting that head injuries may result in significant reductions in self-control (and subsequent increases in antisocial behavior), but additional research capable of disentangling temporal order and addressing selection effects is still necessary.

This limitation is further underscored by previous research showing that individuals with lower overall levels of self-control are significantly more likely to experience situations that increase the probability of sustaining a head injury such as physical fights and car accidents (Andriessen et al., 2011; Jennett, 1996), as well as more risk-taking behaviors in general (Holtfreter, Reisig, & Pratt, 2008; Romer, Duckworth, Sznitman, & Park, 2010). Previous research has also indicated that individuals with lower levels of self-control (Boals, vanDellen, & Banks, 2011; Miller, Barnes, & Beaver, 2011; Moffitt et al., 2011) and greater levels of antisocial behavior tend to disproportionally experience physical health problems (Moffitt et al., 2011; Nedelec & Beaver, 2014). Collectively, these findings suggest that the direction of causality between head injuries and self-control is not well defined, as there are theoretical and empirical findings that support head injuries as both an endogenous and exogenous variable.

4. The current study

The current study aims to begin to address this limitation in the literature by examining the direction of the association between head injuries and impulse control across seven years of development using data from the Pathways study (Mulvey et al., 2004). Since previous research has demonstrated a robust and consistent association between delinquency and subsequent victimization (i.e., the victim-offender overlap; Jennings, Higgins, Tewksbury, Gover, & Piquero, 2010; Lauritsen & Laub, 2007; Lauritsen, Sampson, & Laub, 1991), the current study aims to also examine the direction of the association between head injuries and delinquency across the same period of time. In order to assess the magnitude and direction of association between head injuries, self-control, and delinquency, the current study employs autoregressive cross-lagged path models, which make use of panel data to examine the extent to which: 1) head injuries at earlier waves predict levels of impulse control and delinquency at later waves; 2) impulse control at earlier waves predicts the odds of sustaining a future head injury; and 3) levels of delinquency predict the odds of sustaining a future head injury. This particular analytic strategy simultaneously estimates all examined pathways, providing additional information on the direction of any detected associations. In addition, the autoregressive component of the estimated models controls for stability in head injury, impulse control, and delinquency from one time period to the next, effectively isolating change in each concept across the examined time period.

5. Methods

5.1. Data

The current study analyzes data from the Pathways, a longitudinal study comprised of 1354 adjudicated youth from Maricopa County, Arizona ($n = 654$) and Philadelphia, Pennsylvania ($n = 700$; Mulvey et al., 2004). Study participants were between the ages of 14 and 17 ($M = 16.55$) at the time of their offense and were adjudicated for a serious felony or misdemeanor. Youth tried in adult court were also eligible for inclusion. In total, the Pathways study is comprised of 11 waves of data collection spanning approximately 7 years (Mulvey, 2012). The first wave of data collection, referred to as the baseline interview, commenced in late 2000 and remained open until early 2003. Youth who met the minimum eligibility requirements and agreed to participate in the study were continually enrolled throughout the entire interview period. The following six waves of data (waves 2–7) were completed in six month intervals (6, 12, 24, 30, and 36 months following the baseline interview). Due to budgetary constraints, the

Table 1
Univariate statistics for all study measures.

	Mean/%	SD	Min.	Max.	N
Head injury (Time 1)					
Time 1 (%)	32.14	–	0	1	1170
Time 2 (%)	3.22	–	0	1	1086
Time 3 (%)	2.55	–	0	1	1059
Time 4 (%)	2.65	–	0	1	1056
Time 5 (%)	2.98	–	0	1	1041
Time 6 (%)	3.40	–	0	1	1028
Time 7 (%)	1.99	–	0	1	1003
Time 8 (%)	2.71	–	0	1	959
Self-control					
Time 1	2.96	0.95	1	5	1167
Time 2	3.20	0.95	1	5	1086
Time 3	3.05	0.94	1	5	1059
Time 4	3.22	0.97	1	5	1056
Time 5	3.25	0.95	1	5	1040
Time 6	3.24	0.98	1	5	1028
Time 7	3.31	0.99	1	5	1004
Time 8	3.34	0.96	1	5	959
Overall delinquency					
Time 1	0.16	0.16	0	0.91	1167
Time 2	0.08	0.12	0	0.82	1086
Time 3	0.07	0.11	0	0.86	1060
Time 4	0.05	0.10	0	0.77	1055
Time 5	0.07	0.11	0	0.59	1038
Time 6	0.07	0.11	0	0.86	1025
Time 7	0.06	0.10	0	0.64	995
Time 8	0.05	0.09	0	0.64	954
Aggressive delinquency					
Time 1	0.14	0.15	0	0.91	1167
Time 2	0.08	0.13	0	0.82	1086
Time 3	0.06	0.11	0	0.82	1060
Time 4	0.05	0.10	0	0.73	1055
Time 5	0.06	0.11	0	0.64	1038
Time 6	0.05	0.10	0	0.82	1025
Time 7	0.05	0.09	0	0.64	995
Time 8	0.04	0.08	0	0.73	954
Covariates (Time 1)					
Early behavioral problems	1.60	1.20	0	5	1170
Exposure to violence	5.49	2.99	0	13	1167
Socioeconomic status (SES)	51.66	12.37	11	77	1164
Wechsler Abbreviated Scale of Intelligence (WASI)	84.48	12.84	55	128	1159
Number of previous incarcerations	3.30	2.28	1	15	1170
Age	16.05	1.16	14	19	1170
Race	–	–	0	1	1170
Caucasian (%)	19.23	–	–	–	225
All other races (%)	80.77	–	–	–	945

remaining four waves of data collection (waves 8–11) were completed in 12 month intervals (48, 60, 72, and 84 months after the baseline interview). Overall levels of sample attrition from wave to wave were relatively low: 6-month interview = 6.57%; 12-month interview = 6.79%; 18-month interview = 9.23%; 24-month interview = 9.08%; 30-month interview = 8.86%; 36-month interview = 9.01%; 48-month interview = 10.27%; 60-month interview = 10.86%; 72-month interview = 13.22%; 84-month interview = 16.25%. Based on the limited prevalence of head injury among Pathways participants (see Table 1), the current study draws from information collected annually (baseline interview, 12, 24, 36, 48, 60, 72, and 84 month follow up interviews). Due to the limited number of females included in the Pathways (n = 184), we follow the lead of previous research and limit the final analytic sample to male offenders with at least partial information on the examined measures (n = 1150; Shulman, Monahan, & Steinberg, 2017).

During each interview, questions were asked tapping six general domains: 1) background characteristics; 2) individual functioning; 3) psychosocial development and attitudes; 4) family context; 5) personal relationships; and 6) community context (Schubert et al., 2004). These six domains are comprised of a wide range of focal concepts directly related to various aspects of development including overall physical and mental health, delinquent and deviant behavior, peer interactions, and romantic relationships. Many of the primary concepts of interest related to each of the six examined domains were measured across all study periods (i.e., baseline through 84 month follow up interview), making it possible to investigate changes and stability in such concepts over the entire study period. To obtain as much background information as possible, the baseline interview was split into two 2-hour sessions and included both current and retrospective information on the main study concepts. All subsequent interviews were more centrally focused on documenting changes since the last interview period and included a single 2-hour interview session. Additional information related to sampling procedures, sample composition, and measurement instruments has been documented previously (Mulvey et al., 2004; Schubert et al., 2004).

5.2. Measures

5.2.1. Head injury

Head injuries were assessed at each interview with a single, self-reported question asking participants whether they had been hit in the head so hard that it resulted in unconsciousness or required medical attention. During the baseline interview, participants were asked if they had sustained a head injury meeting the description provided at any point previously. At each follow up interview (12- through 84-month follow up periods), participants were asked if they had sustained such an injury since the last interview, with the resulting measures reflecting any new injuries over the past 12 months. Responses to all head injury measures were coded dichotomously, such that 0 = *no* and 1 = *yes*. Descriptive statistics for all head injury measures and other measures examined in the current study are presented in Table 1.

5.2.2. Impulse control

Following the lead of previous studies analyzing the Pathways data (Barnes et al., 2016; Sullivan & Loughran, 2014; Walters, 2014), impulse control was assessed using the impulse control subscale of the Weinberger Adjustment Inventory (WAI; Weinberger & Schwartz, 1990). The WAI is a standardized measure comprised of 23 items tapping four related subscales: impulse control; suppression of aggression; consideration of others; and temperance. The impulse control subscale is comprised of eight items tapping overall behavioral control (e.g., I say the first thing that comes to my mind without thinking enough about it). Participants were asked to rank how closely their behavior and attitudes resembled each statement over the past six months using five response categories ranging from 1 (*false*) to 5 (*true*). Responses to each of the eight items were averaged (α = 0.76 at the baseline interview) separately across each interview period and coded such that higher values reflected greater overall levels of impulse control. Participants with missing values on three or more of the eight items used to create the index were coded as missing by the Pathways research team, but levels of missingness were extremely limited and displayed as follows (excluding sample attrition): baseline interview = 0.22%; 12-month interview = 0.00%; 24-month interview = 0.00%; 36-month interview = 0.00%; 48-month interview = 0.07%; 60-month interview = 0.00%; 72-month interview = 0.00%; 84-month interview = 0.00%.

5.2.3. Delinquency

Delinquency was assessed at each wave using an adapted version of the self-reported delinquency scale developed by Huizinga, Esbensen, and Weiher (1991). During each interview period, participants reported whether they had engaged in 22 different delinquent activities since the last interview period.[2] The reported acts tapped both violent (e.g.,

[2] During the baseline interview, participants were asked to report on behaviors over a

taken something by force using a weapon) and nonviolent (e.g., damaged or destroyed property that did not belong to you) forms of delinquent behavior, and similar measures have been used in previous research analyzing the Pathways data (Loughran, Paternoster, Piquero, & Pogarsky, 2011; Monahan, Steinberg, Cauffman, & Mulvey, 2013; Piquero, Monahan, Glasheen, Schubert, & Mulvey, 2012; Walters, 2014). Since previous studies have identified physical fights and other forms of aggressive behavior as a potential source of head injury among adolescents (Fishbein et al., 2016; Grafman et al., 1996; Jennett, 1996; Kim et al., 1999; Rao et al., 2009; Tateno et al., 2003), a second delinquency subscale comprised of 11 items tapping more aggressive forms of delinquency such as getting into a physical fight and physically beating someone bad enough to require medical attention, was also included in the current study.[3] For both delinquency measures, responses to all items were coded dichotomously such that 0 = *behavior did not occur during the recall period* and 1 = *behavior did occur during recall period*. For the overall delinquency measure, responses to all 22 items were then averaged to reflect the proportion of all acts each participant engaged in during the recall period, with the resulting measure ranging between 0 (no delinquent acts) and 1 (all delinquent acts). The same coding strategy was also employed for the aggressive delinquency items. Importantly, both the overall and aggressive delinquency measures employed in the current study reflect the overall variety of offenses participants engaged in at each interview period. Variety offending scores were used in the current study for three reasons: 1) the frequency offending measures constructed by the Pathways team displayed significant levels of skew and overdispersion allowing for the use of a broader range of analytic strategies; 2) variety scores minimize recall bias and telescoping, resulting in increased levels of accuracy; and 3) variety scores are not compromised by high frequency, non-serious forms of criminal behavior (e.g., petty theft). Perhaps even more importantly, a number of previous studies have advocated for the use of variety indices over frequency indices (Moffitt, Caspi, Rutter, & Silva, 2001; Piquero et al., 2012; Sweeten, 2012), and additional studies analyzing the Pathways data have reported a strong concordance between frequency and variety offending scores (Brame, Fagan, Piquero, Schubert, & Steinberg, 2004; Knight, Little, Losoya, & Mulvey, 2004; Piquero et al., 2012). For these reasons, the current study relies on variety offending measures as opposed to frequency offending measures.

5.2.4. Statistical covariates

To better isolate the associations between head injury, self-control, and delinquency, a total of seven covariates were included in the estimated analyses. First, a measure of early behavior problems was assessed using five items from the Psychopathy Checklist–Youth Version (Forth, Kosson, & Hare, 2003). Participants were asked to indicate whether they had engaged in five different deviant behaviors (cheating, disturbing class, stealing, and fighting) before they were 11 years old. Responses were coded dichotomously (0 = *no* and 1 = *yes*) and summed to create a variety index with responses ranging between 0 and 5 ($M = 1.60$, $SD = 1.20$). The second covariate included in the analyses tapped overall exposure to violence using the Exposure to Violence Inventory (ETV; Selner-O'Hagan, Kindlon, Buka, Raudenbush, & Earls, 1998), a 17-item measure reflecting a broad range of experiences that each participant either witnessed happen to another person or experienced themselves at any time prior to the baseline interview. Responses to each item were coded dichotomously and then summed to reflect the overall number of violent situations each participant witnessed or experienced ($M = 5.49$, $SD = 2.99$). Third, a count of the total number of arrests prior to the baseline interview was also included as a statistical covariate ($M = 3.30$, $SD = 2.28$). Fourth, a measure of each participant's socioeconomic status (SES) was calculated in line with Hollingshead's (1971) Index of Social Positions using parental occupational prestige and educational attainment during the baseline interview, with higher scores reflecting higher overall levels of SES (Mulvey et al., 2004; $M = 51.66$, $SD = 12.37$). Fifth, intelligence was measured using a paper version of the Wechsler Abbreviated Scale of Intelligence (WASI; Wechsler, 1999), a validated and commonly used measure of IQ ($M = 84.48$, SD = 12.84). Sixth, age was calculated based on each participant's date of birth and was coded continuously in years ($M = 16.05$, $SD = 1.16$). Seventh and finally, race was coded dichotomously such that 0 = *Caucasian* and 1 = *all other races*.

5.3. Plan of analysis

The plan of analysis was carried out in three interrelated steps. First, Spearman rank-order correlations were estimated to examine overall stability in impulse control, overall delinquency, and aggressive delinquency. These preliminary analyses are essential, as the results will estimate the stability or variability in these concepts over time. High levels of stability (i.e., larger Spearman correlation coefficients) would indicate that experiences (including sustaining a head injury) occurring between each interview period have limited impact on subsequent levels of impulse control or delinquency. Alternatively, greater levels of variability (i.e., smaller Spearman correlation coefficients) within each of the examined concepts across the examined timeframe would provide preliminary evidence of meaningful change, allowing for subsequent models aimed at identifying more specific sources of influence. In addition, low levels of stability would render autoregressive models unnecessary, as such models include controls for stability in the examined measures from one examination period to the next. Alternatively, evidence of stability across the examined timeframe would provide support for the use of autoregressive models in an effort to better isolate variability in the examined measures over time.

Assuming that the impulse control and delinquency measures vary across time, the next step of the analysis involves the estimation of a series of autoregressive cross-lagged models in which head injuries at earlier waves (e.g., Time 1) were used to predict later (e.g., Time 2) measures of impulse control and delinquency. The employed models also included controls for stability in each of the examined measures from one time point to another, effectively isolating change. Cross-lagged models offer unique advantages over other longitudinal modeling techniques (e.g., growth curve models and group-based trajectory models) as they allow for a estimation of the *direction* of longitudinal associations, providing preliminary information on temporal order. Alternatively, other longitudinal approaches such as growth curve

(*footnote continued*)
broader timeframe. More specifically, participants were asked to report whether they had engaged in each of the 22 behaviors over their entire lifetime. Based on the length and timing of this recall period, it was difficult to ensure that head injuries and levels of self-control reported at the baseline interview reflected experiences that occurred prior to the reported delinquent acts, effectively compromising temporal ordering. To address this limitation and better align the baseline delinquency measure with the baseline head injury and self-control measures, additional follow-up items were used to limit baseline delinquency to acts that occurred in the past six months. Participants who indicated that they engaged in a given delinquent act during their lifetime at the time of the baseline interview were then asked to report the last time they engaged in each reported behavior. Responses were coded on a four-point scale as follows: 1 = *within the past 30 days*; 2 = *1–3 months ago*; 3 = *4–6 months ago*; and 4 = *> 6 months ago*. These items were then recoded to reflect whether each participant had engaged in each act during the past six months (coded as 1) or whether the reported act occurred more than six months prior to the baseline interview (coded as 0). To test the robustness of the pattern of results reported in the current study, sensitivity analyses using the lifetime delinquency measures at the baseline interview were also conducted (results not presented, but available upon request). The overall pattern of results did not differ in any substantive way from those reported in the current study.

[3] Importantly, a nonviolent or income delinquency measure is also available in the Pathways study (for more information see Mulvey et al., 2004). However, this subscale was omitted from the current study since such forms of delinquency are not likely to result in increases in the odds of sustaining a future head injury. While it remains possible that head injuries may increase the likelihood of engaging in nonviolent forms of delinquency, the reverse hypothesis seems implausible. For this reason, the analysis in the current study is focused more directly on overall and aggressive delinquency.

modeling, would allow for the direct estimation of the association between sustaining a head injury and overall changes in impulse control or delinquency over time, but could not provide direct estimates of the direction of the association (i.e., whether head injuries result in lower levels of impulse control, or whether individuals with lower levels of impulse control are more likely to sustain subsequent head injuries). In order to address the alternative hypothesis, that changes in delinquency or impulse control contribute to changes in the likelihood of sustaining a head injury, the models also simultaneously estimated associations between earlier measures of impulse control and delinquency and later measures of head injuries while also controlling for stability in all three variables. Significant associations in this latter portion of the model would provide preliminary evidence of selection processes in which impulse control and delinquency are likely contributing to the overall likelihood of suffering subsequent head injuries.[4] Cross-lagged models were estimated for overall delinquency and aggressive delinquency separately. All analyses were performed in *Mplus* 7.4 (Muthén & Muthén, 1998–2012) using maximum likelihood estimation and robust standard errors. Model fit was assessed using the following indices (Hu & Bentler, 1999): comparative fit index (CFI, values ≥ 0.95 indicate close fit and values ≥ 0.90 indicate acceptable fit); Tucker-Lewis index (TLI, interpreted similar to CFI); and root mean square error of approximation (RMSEA, values ≤ 0.05 indicate a close fit and values ≤ 0.10 indicate acceptable fit). Missing values were handled using full information maximum likelihood (FIML) estimation, which imputes missing values based on all available observed information.

6. Results

The first step of the analysis involved estimating Spearman rank-order correlations for the employed impulse control measures. The resulting matrix is presented in Table 2. Directly in line with Cohen's (1992) guidelines, the examined impulse control measures demonstrated moderate ($r > 0.30$, but $r < 0.50$) to high ($r > 0.50$) levels of stability across the entire study period, with correlation coefficients ranging from 0.43 ($p < 0.001$; impulse control at Time 1 with impulse control at Time 8) to 0.70 ($p < 0.001$; impulse control at Time 5 with impulse control at Time 6). Importantly, stability in impulse control seemed to diminish as the amount of time between measures increased. However, the correlation between impulse control assessed during the baseline interview (i.e., Time 1) and the latest interview period (i.e., Time 8) still demonstrated moderate levels of stability ($r = 0.43$, $p < 0.001$). Importantly, while impulse control demonstrated patterns of stability across all eight measurement periods, it is also worth noting that impulse control was not perfectly stable, and exhibited levels of meaningful change even from one measurement period to the next. Despite this pattern of results, two possibilities surrounding the association between head injuries and impulse control remain possible. First, head injuries may be responsible for disrupting stability in impulse control and creating increased levels of variability over time. Second, and alternatively, changes in impulse control stemming from other sources may increase the overall likelihood of sustaining a subsequent head injury.

The next step of the analysis involved the estimation of Spearman rank-order correlations for the overall and aggressive delinquency measures. The results of this stage of the analysis are presented in Table 3. The coefficients presented above the diagonal reflect stability estimates for the overall delinquency measure across all eight time points. As can be seen from the correlation matrix, and also in line with Cohen's (1992) guidelines, the overall delinquency measure displayed

Table 2
Spearman rank order correlation coefficients for impulse control measures.

	1.	2.	3.	4.	5.	6.	7.	8.
1. Time 1	–							
2. Time 2	0.52**	–						
3. Time 3	0.51**	0.53**	–					
4. Time 4	0.48**	0.55**	0.62**	–				
5. Time 5	0.47**	0.51**	0.53**	0.66**	–			
6. Time 6	0.48**	0.50**	0.51**	0.64**	0.70**	–		
7. Time 7	0.48**	0.52**	0.51**	0.59**	0.65**	0.67**	–	
8. Time 8	0.43**	0.49**	0.50**	0.61**	0.62**	0.64**	0.67**	–

** $p < 0.01$.

Table 3
Spearman rank order correlation coefficients for overall and aggressive delinquency measures.

	1.	2.	3.	4.	5.	6.	7.	8.
1. Time 1	–	0.33**	0.30**	0.21**	0.22**	0.16**	0.21**	0.19**
2. Time 2	0.34**	–	0.40**	0.34**	0.33**	0.30**	0.28**	0.25**
3. Time 3	0.29**	0.32**	–	0.40**	0.31**	0.32**	0.30**	0.29**
4. Time 4	0.19**	0.29**	0.35**	–	0.43**	0.38**	0.32**	0.29**
5. Time 5	0.24**	0.30**	0.29**	0.38**	–	0.45**	0.42**	0.37**
6. Time 6	0.19**	0.28**	0.30**	0.33**	0.38**	–	0.43**	0.37**
7. Time 7	0.21**	0.29**	0.21**	0.24**	0.35**	0.33**	–	0.39**
8. Time 8	0.20**	0.27**	0.22**	0.23**	0.30**	0.29**	0.29**	–

Note: Correlation coefficients for overall delinquency measures reported above the diagonal and coefficients for aggressive delinquency reported below the diagonal.
** $p < 0.01$.

low ($r > 0.10$, but $r < 0.30$) to moderate levels of stability across the examined timeframe. Similar to the findings for impulse control, stability in levels of overall delinquency decreased as more time elapsed between the examined measures. For example, the correlation between overall delinquency at Time 1 and Time 2 was 0.33 ($p < 0.001$), but the correlation between overall delinquency at Time 1 and Time 8 was 0.19 ($p < 0.001$). Despite these systematic decreases, the overall pattern of results indicated low to moderate levels of stability in overall delinquency with estimates ranging from 0.16 ($p < 0.001$; overall delinquency at Time 1 and Time 6) to 0.45 ($p < 0.001$; overall delinquency at Time 5 and Time 6). A similar pattern of results was also observed for the aggressive delinquency measure (results presented below the diagonal). Stability appeared to decrease as more time between measurements elapsed, but the overall pattern of results demonstrated low to moderate levels of stability in aggressive delinquency with correlation coefficients ranging from 0.19 ($p < 0.001$; overall delinquency at Time 1 and Time 4, as well as, Time 1 and Time 6) to 0.38 ($p < 0.001$; Time 4 and Time 5, as well as, Time 5 and Time 6).

Since the results of the Spearman rank-order correlations demonstrated sufficient variation in impulse control, overall delinquency, and aggressive delinquency, the next stage of the analysis involved estimating bidirectional cross-lagged models to better distinguish between causal and selection effects. The first cross-lagged model examined the associations between head injury, impulse control, and overall delinquency. The model provided a close fit to the data (CFI = 0.96, TLI = 0.91, and RMSEA = 0.03) and is presented in Fig. 1. As a reminder, the standardized path estimates presented in the Figure were adjusted for all measured covariates (early behavior problems, exposure to violence, number of previous incarcerations, SES, IQ, age, and sex). As can be seen, impulse control and overall delinquency demonstrated a considerable amount of stability from one time to the next. Head injury demonstrated a less consistent pattern of stability, but the cross-lagged models revealed four significant stability coefficients (Time 1 to Time 2, Time 3 to Time 4, Time 4 to Time 5, and Time 5 to Time 6), indicating that individuals who sustained a previous head injury were at an

[4] The estimated cross-lagged models did not include direct paths from impulse control to delinquency. Additional models including these paths resulted in convergence issues and were not able to be estimated. Due to this limitation, the final models were limited to the direct paths displayed in Figs. 1 and 2 and the paths between impulse control and delinquency were omitted.

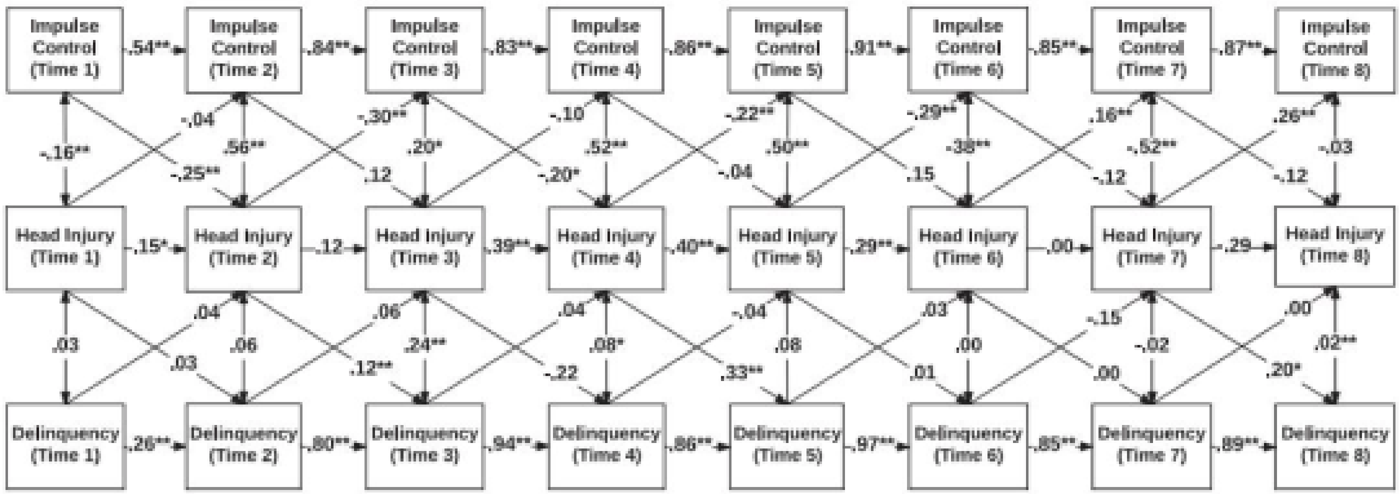

Fig. 1. Results of cross-lagged path model examining longitudinal associations between head injury, impulse control, and overall delinquency.
Note: Standardized coefficients presented. All paths estimated with the following covariates: a) early behavior problems; b) exposure to violence; c) socioeconomic status; d) number of previous incarcerations; e) Wechsler Abbreviated Scale of Intelligence (WASI); f) age; and g) sex.
Model Fit Statistics: $\chi^2 = 488.97(214)$, $p < 0.001$; CFI = 0.96; TLI = 0.91; RMSEA = 0.03.
$N = 1150$.
$^*p < 0.05$; $^{**}p < 0.01$.

increased risk for sustaining an additional injury in the future. The cross-lagged paths estimated the associations between head injuries, impulse control, and delinquency across all eight time points. These paths revealed some evidence of selection, with lower levels of impulse control at Time 1 predicting a greater likelihood of sustaining a head injury at Time 2 ($\beta = -0.25$, $p < 0.001$) and a similar pattern of results for Time 3 impulse control and Time 4 head injury ($\beta = -0.20$, $p = 0.016$). The association between Time 2 impulse control and Time 3 head injury was positive, indicating that individuals with greater overall levels of impulse control were at an increased risk for sustaining a head injury, but the association did not reach conventional levels of statistical significance ($\beta = 0.12$, $p = 0.155$). A similar pattern of results was observed for Time 5 impulse control and Time 6 head injury ($\beta = 0.12$, $p = 0.102$). Despite this pattern of results, overall levels of delinquency did not result in significant increases in the likelihood of subsequently sustaining a head injury.

The cross-lagged paths revealed more consistent evidence suggesting that sustaining a head injury was associated with significant decreases in impulse control across multiple time points including Time 2 head injury and Time 3 impulse control ($\beta = -0.30$, $p < 0.001$), Time 4 head injury and Time 5 impulse control ($\beta = -0.22$, $p < 0.001$), and Time 5 head injury and Time 6 impulse control ($\beta = -0.29$, $p < 0.001$). Head injury at Time 6 was also found to be positively associated with impulse control at Time 7 ($\beta = 0.21$, $p < 0.001$) and head injury at Time 7 and was also positively associated with increased levels of impulse control at Time 8 ($\beta = 0.26$, $p < 0.001$). Finally, the cross-lagged paths also revealed significant increases in overall delinquency following a head injury at Time 2 ($\beta = 0.12$, $p < 0.001$), Time 4 ($\beta = 0.33$, $p < 0.001$), and Time 7 ($\beta = 0.20$, $p = 0.049$).

The final stage of the analysis involved the estimation of another bidirectional cross-lagged model that included the aggressive delinquency measures. The resulting model provided a close fit to the data (CFI = 0.96, TLI = 0.91, and RMSEA = 0.03) and is presented, along with all accompanying standardized path estimates, in Fig. 2. Similar to the previous model examining overall delinquency, the impulse control and aggressive delinquency measures displayed relatively consistent levels of stability, while the head injury measure demonstrated a less consistent pattern of stability. Once again, the cross-lagged paths revealed preliminary evidence of selection effects with lower levels of impulse control at Time 1 resulting in a greater likelihood of sustaining a head injury at Time 2 ($\beta = -0.19$, $p < 0.001$), and a similar pattern of results for impulse control at Time 3 and head injury at Time 4 ($\beta = -0.29$, $p < 0.001$). Similar to the cross-lagged model examining overall delinquency, levels of aggressive delinquency did not significantly increase the odds of sustaining a subsequent head injury at any of the examined time points.

The cross-lagged paths revealed more consistent associations between head injuries and subsequent decreases in impulse control, with this particular pattern of results reflected across head injury at Time 2 and impulse control at Time 3 ($\beta = -0.31$, $p < 0.001$), head injury at Time 3 and impulse control at Time 4 ($\beta = -0.23$, $p < 0.001$), head injury at Time 4 and impulse control at Time 5 ($\beta = -0.23$, $p < 0.001$), and head injury at Time 5 and impulse control at Time 6 ($\beta = -0.35$, $p < 0.001$). The association between sustaining a head injury at Time 7 and levels of impulse control at Time 8 were also significantly associated, but the association was positive ($\beta = 0.23$, $p < 0.001$), indicating that subsequent levels of impulse control increased. The cross-lagged paths examining the association between sustaining a head injury and subsequent increases in aggressive delinquency revealed a less consistent pattern of results, with significant associations between head injury at Time 2 and aggressive delinquency at Time 3 ($\beta = 0.10$, $p < 0.001$). Importantly, sustaining a head injury at Time 3 was significantly associated with aggressive delinquency at Time 4, but the association was negative, indicating that levels of aggressive delinquency decreased ($\beta = -0.12$, $p < 0.001$).

7. Discussion

Self-control has emerged as one of the most robust predictors of antisocial behavior identified in contemporary criminological research, with multiple meta-analyses identifying moderately-sized, consistent associations between self-control and antisocial behavior (de Ridder et al., 2012; Pratt & Cullen, 2000; Vazsonyi et al., 2017). Based on the consistency of this finding, more recent advances in criminological research on self-control theory has focused on additional aspects of the theory including the etiological development of self-control across different stages of the life-course. With this in mind, the current study aimed to contribute to this growing body of literature by more closely examining the extent to which sustaining a head injury during adolescence and early adulthood contributes to meaningful changes in one specific dimension of self-control—impulse control. Directly in line

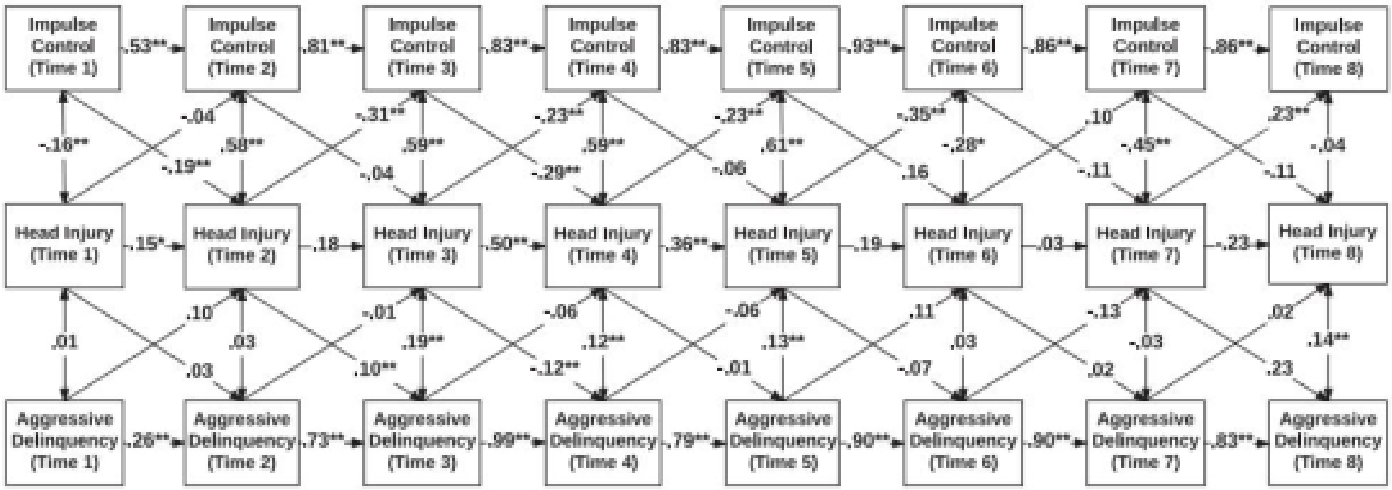

Fig. 2. Results of cross-lagged path model examining longitudinal associations between head injury, impulse control, and aggressive delinquency.

Note: Standardized coefficients presented. All paths estimated with the following covariates: a) early behavior problems; b) exposure to violence; c) socioeconomic status; d) number of previous incarcerations; e) Wechsler Abbreviated Scale of Intelligence (WASI); f) age; and g) sex.

Model Fit Statistics: $\chi^2 = 472.54(208)$, $p < 0.001$; CFI = 0.96; TLI = 0.91; RMSEA = 0.03.

$N = 1150$.

$^*p < 0.05$; $^{**}p < 0.01$.

with this objective, the current study employed a series of cross-lagged autoregressive path models to more effectively establish temporal order and examine the extent to which lower overall levels of self-control (and greater levels of delinquent behavior) predispose individuals to subsequent head injuries. The results revealed three primary findings, all of which warrant additional discussion.

The first key finding to emerge from the current study was that the overall pattern of results from the path models aligned more closely with a causal effect of head injury on changes in impulse control, such that head injuries were associated with significant decreases in subsequent levels of impulse control. While these findings do not produce unequivocal evidence that sustaining a head injury results in subsequent changes in impulse control, they do increase confidence in such a conclusion due to both the strength of the employed statistical design and the consistency of this pattern of results. The use of cross-lagged autoregressive path models ensures that examined head injuries occur before changes in impulse control, while also controlling for stability in impulse control from one examined time period to the next. Based on this pattern of results, the findings of the current study directly align with previous studies reporting a significant association between sustaining a head injury and lower overall levels of impulse control (and similar concepts, such as executive functioning; Dikmen et al., 2009; Polito et al., 2010; Rohling et al., 2009; Schwartz et al., 2017). However, the current study also augments these findings by ensuring that such changes in impulse control occurred *after* sustaining a new head injury.

The results of the path models also indicated significant cross-lagged paths between head injury at Time 6 and impulse control at Time 7 (in the model examining overall delinquency), as well as head injury at Time 7 and impulse control at Time 8 (in both estimated path models). The resulting associations, however, were positive, indicating that males who sustained head injuries were significantly more likely to display *increases* in impulse control across the two time periods. While only speculative, this pattern of findings may have emerged because of the low overall prevalence of head injuries at Times 7 (1.99%) and 8 (2.71%), which may lead to inconsistent findings and increase the likelihood of Type I error. Alternatively, previous research has indicated that impulse control tends to develop in a linear pattern, continually increasing during adolescence and into early adulthood (Steinberg, 2007, 2008; Steinberg et al., 2017; Harden & Tucker-Drob, 2011). Directly in line with this observation, it may be the case that based on the participants' ages during Times 7 ($M_{Age} = 22.03$, $SD = 1.15$) and 8 ($M_{Age} = 23.03$, $SD = 1.15$) overall levels of impulse control may be increasing at such a rapid pace that such levels are relatively robust to head injuries, particularly less serious injuries. In other words, the normative developmental pattern of impulse control during this period of the life course (i.e., early adulthood) may be far more robust to environmental insults compared to levels earlier in the life course (i.e., childhood and adolescence).

Another possibility is that due to extremely high levels of stability in impulse control, the vast majority of the variation in impulse control may be explained by time-stable characteristics (such as personality traits or genetic influences), leaving little residual variation to be explained by additional influences like head injury. This possibility is further underscored by the large standardized stability path estimates observed in both path models, many of which exceeded 0.80. While these stability coefficients seem quite large, this pattern of findings converges with Gottfredson and Hirschi's (1990) classic arguments advocating for relative stability over the life course. In addition, the increasing levels of stability observed in the latter study periods seem to align with recent arguments by both Steinberg (2007, 2008), Steinberg et al. (2017) and Pratt (2016) who both attempted to more directly align the development of self-control with the age-crime curve. In this way, self-control may continue to increase across the latter stages of the life course, but such increases would not continue indefinitely. Just as the propensity to engage in criminal behavior decreases across the latter stages of the life course, such decreases eventually plateau. A similar pattern in the development of self-control would result in more consistent levels of self-control as one ages, resulting in larger stability coefficients during adulthood compared to adolescence. This possibility remains speculative and additional research would benefit from providing a more fine-tuned examination of the longitudinal development of self-control.

The second finding to emerge from the current study was a relatively inconsistent association between sustaining a head injury and subsequent increases in delinquency. Based on the results of previous studies reporting a significant and positive association between sustaining a head injury and increased levels of delinquency (Behnken et al., 2015; Farrer & Hedges, 2011; Fishbein et al., 2016), this finding was also relatively unexpected. However, the inconsistent association between head injuries and delinquency may reflect the presence of an indirect pathway, in which changes in impulse control following a head injury may result in increased levels of delinquency. This possibility is supported by findings from previous research indicating that sustaining a head injury can result in impaired cognitive ability, attention, working memory, language fluidity, information processing speed, and even reductions in executive functioning (Dikmen et al., 2009; Polito et al., 2010; Rohling et al., 2009). Also in line with this possibility, previous studies have indicated that head injuries may result in increased levels of antisocial behavior via their impact on underlying beliefs and attitudes toward aggression and violence (e.g., Cristofori et al., 2016; Fishbein et al., 2016). In addition, Schwartz et al. (2017), also examining the Pathways sample, found that sustaining a head injury resulted in short-term decreases in self-control, which, in turn, increased the odds of future levels of aggressive delinquency. While the authors attempted to maintain temporal order in their models, since the results were more focused on changes in self-control and delinquency, it was not possible to ensure that head injures preceded changes in self-control, which, in turn, preceded changes in delinquency. Despite these limitations, these findings indicate that changes in impulse control may be a mechanism through which head injuries result in changes in behavioral outcomes. Future research would benefit from continuing to examine this indirect pathway more directly with a careful eye toward maintaining temporal order.

Third, and finally, the estimated path models revealed little to no evidence of selection effects, as lower levels of impulse control and increased levels of delinquent behavior did not appear to consistently result in increased odds of sustaining a future head injury. However, the results of both path models indicated that lower levels of impulse control at Times 1 and 3 resulted in significant increases in the odds of sustaining a subsequent head injury. These findings suggest that lower levels of impulse control at earlier stages of the life course may be more influential in the underlying selection processes that are ultimately related to sustaining a head injury. This possibility is further underscored by research that builds off Gottfredson and Hirschi's (1990) original conceptualization and indicates that overall levels of self-control are relatively low during adolescence and gradually increase as youth transition into adulthood (Steinberg, 2008). This developmental pattern was also recently recognized by Pratt (2016), who directly tied the development of self-control to the age-crime curve and noted that self-control "is lower during the crime-prone years, increases thereafter, and shadows the rage of offending over the life course" (p. 133). Collectively, these findings suggest that since self-control is increasing across the examined period of the life course, the impulsive and risk-taking behaviors that characterize adolescence may also contribute to the likelihood of sustaining a head injury during this same period of development, but that such risks subside over time. Finally, these findings also provide preliminary evidence suggesting that a potential feedback loop between head injuries and impulse control may also exist in which lower levels of impulse control increase the likelihood of sustaining a head injury, which, in turn, results in subsequently lower levels of impulse control and so on. Future research would also benefit from exploring this possibility more closely, as potential interventions aimed at either increasing impulse control early in the life course (e.g., Piquero, Piquero, & Underwood, 2016) or prioritizing the monitoring and treatment of early head injuries may break the cycle and significantly decrease the likelihood of future criminal behavior. Previous research has identified neurofeedback, wherein patients learn to control cognitive functioning through the use of brain monitoring equipment and specialized software, as a potentially effective intervention for individuals who have suffered a brain injury (May, Benson, Balon, & Boutros, 2013). Additional research has pointed to pharmacological interventions (Lauterbach, Notarangelo, Nichols, Lane, & Koliatsos, 2015), cognitive behavioral therapy (Fann et al., 2015), and as well as other cognitive rehabilitation treatment programing (e.g., Memory and Attention Adaptation Training [MAAT] and Attention Builders Training [ABT]) as effective treatment options (McDonald et al., 2017).

Despite these contributions to the existing literature, the results of the current study should be viewed with caution due to the presence of several limitations. First, the employed head injury measure is quite broad and does not provide information on the severity, timing, or treatment of sustained injuries. This information is important and would provide greater insight into associations between head injuries, impulse control, and delinquency, as such characteristics likely moderate any examined associations (Schretlen & Shapiro, 2003). Second, and directly related, the amount of time that elapsed between sustaining a head injury and the assessment of impulse control at each time period may mask more pronounced, initial changes in impulse control. More specifically, the results of a previous meta-analysis revealed a moderately sized association between a mild traumatic brain injury and a range of neuropsychological functioning within a week of sustaining the injury ($d = -0.39$); however, the results dissipated relatively quickly resulting in nonsignificant effects within three months after sustaining an injury (Rohling et al., 2009). These results indicate that relatively minor head injuries (which are the most common) may have a limited and short-term impact on impulse control that diminishes as part of the normal recovery process. The results of an additional meta-analysis indicated that the impact of more severe or serious injuries on cognitive impairments may linger for more than six months (Dikmen et al., 2009). Since the head injury measures used in the current study did not include information on the severity of injury, it is likely that the pattern of results observed are tempered by this pattern of results, potentially masking additional associations between head injuries and decreases in impulse control. For this reason, future research would benefit from more detailed information surrounding each head injury (such as severity and timing) in an effort to better understand the association between sustaining such an injury and subsequent long- and short-term changes in impulse control.

Third, the Pathways sample is comprised of juveniles who were previously convicted of a serious offense, which can provide a much fuller understanding of the underlying etiological development of delinquent behaviors, but also limits the generalizability of the findings from the current study. Future research would benefit from replicating these findings within a more heterogeneous sample that generalizes to a larger population. Directly in line with this limitation, due to the limited number of females in the Pathways sample ($n = 184$), the current study was limited to males. Since males are about twice as likely as females to experience a head injury (Frost, Thomas, Primosch, & Hedges, 2013), these findings have potentially important implications, but examining similar associations within females is a necessary extension that would benefit the existing literature. Fourth, and finally, based on data limitations of the Pathways sample, we were unable to examine direct measures of executive function, such as neuroimaging data, to more directly examine changes in the structure and function of specific brain regions following a head injury. Including more direct and precise measures of executive functions would provide additional insight into the manner in which head injuries ultimately contribute to meaningful changes in both impulse control and antisocial behavior.

Despite these limitations, the current study demonstrates the underlying complexity of the etiological development of self-control. As has been pointed out in previous research, self-control is an inherently biosocial concept (Beaver et al., 2007; DeLisi, 2014; Hay & Meldrum, 2016), with biological and environmental influences working together to shape individual differences in overall levels of self-control. The current study contributes to these findings by identifying a single source of environmental influence—head injuries—that further demonstrates the interconnected nature of both sources of influence. In this way, an *environmental* source of influence operates through *biological* mechanisms to impact antisocial behavior. While the results of the current study align with previous research indicating that head injuries are a promising etiological factor, this broader finding suggests that there are likely many other sources of environmental influence that operate in a similar manner. Future research will benefit from not only identifying similar sources, but also demonstrating the way that such sources work with biological predispositions (as well as, through biological mechanisms) to result in behavioral variability.

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Head Injuries and Changes in Delinquency from Adolescence to Emerging Adulthood: The Importance of Self-control as a Mediating Influence

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Abstract

Objectives: The current study examines whether head injuries suffered earlier in the life course are associated with subsequent changes in self-control and delinquency. *Methods:* Latent growth curve models and path analysis are used to analyze the developmental trajectories of self-control and delinquency as well as the potential associations between head injury, self-

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control, and delinquency among a sample of youth offenders from the pathways to desistance study. *Results:* The results revealed significant associations between head injuries and short-term changes in self-control and subsequent increases in aggressive delinquency. Indirect pathway models revealed that lower levels of self-control significantly mediated the association between head injuries and starting levels in aggressive delinquency. The association between head injuries and changes in aggressive delinquency was also significantly mediated by self-control, but the association was negative, indicating that youth who previously suffered head injuries desisted from aggressive delinquency at a slightly faster rate than their noninjured peers. Additional analyses revealed that, despite accelerated rates of decline, injured youth engaged in significantly higher levels of aggressive delinquency throughout the entire observation period. *Conclusion:* Head injuries represent one environmental factor that may influence delinquent behaviors through their influence on biological and developmental processes.

Keywords
head injuries, self-control, delinquency, desistance, adolescence

Previous research has documented robust associations between various forms of self-control and an assortment of detrimental outcomes, ranging from delinquency and antisocial behavior (Hay and Meldrum 2016; de Ridder et al. 2012; Vazsonyi, Mikuška, and Kelley 2017) to victimization (Pratt et al. 2014) and even negative physical and mental health outcomes (Moffitt et al. 2011). Findings from studies employing different conceptualizations and measures of self-control converge to reveal that individuals with lower levels of self-control (Hay and Meldrum 2016; de Ridder et al. 2012; Vazsonyi et al. 2017) and greater levels of impulsivity and sensation seeking (Harden, Quinn, and Tucker-Drob 2012; Meier et al. 2008) are significantly more likely to engage in various forms of delinquent and antisocial behaviors. Despite these findings, the precise sources of within- and between-individual variability in self-control remain in question. While a developed line of research has pointed to various socialization processes that might impact self-control (Burt, Simons, and Simons 2006; Gibson et al. 2010; Pratt, Turner, and Piquero 2004; Turner, Piquero, and Pratt 2005), other studies have focused on biological factors including genetic influences (Niv et al. 2012), structural and functional variation within specific brain regions (Grant and Kim 2014; Jimura, Chushak, and Braver

2013), and other neurobiological (Konicar et al. 2015) and developmental processes (Harden and Tucker-Drob 2011; Steinberg et al. 2008).

These findings indicate that sources contributing to the development of self-control are likely complex and include a combination of environmental, biological, and developmental factors. Such findings also seem to indicate that these influences work collectively, with some potent environmental influences potentially operating through the physical disruption of normal neurobiological development or functioning to produce variability in self-control. One such example is head injury (HI), which previous studies have linked to both structural and functional changes in various brain regions that have been directly linked to levels of self-control and related concepts (Knutson et al. 2014; Shenton et al. 2012). Individuals who suffer HIs have been found to display increases in externalizing problems such as aggression and aggressive behavior (Fishbein et al. 2014; Perron et al. 2015; Rao et al. 2009) and have also been found to suffer disproportionally from neurobiological deficits associated with cognitive changes related to self-control including diminished executive functioning (Knutson et al. 2014; Shenton et al. 2012) and emotional dysregulation (Fishbein et al. 2014). These findings, in conjunction with the results from studies documenting the effects of HIs on other measures of cognitive functioning (Dikmen et al. 2009; Polito, Thompson, and DeFina 2010), provide preliminary evidence that diminished levels of self-control may ultimately contribute to the association between HIs and subsequent criminal behavior.

The current study contributes to the extant literature in three ways. First, while previous studies have examined associations between HIs, various measures of self-control, and antisocial behavior in adulthood, fewer studies have examined such associations in the critical developmental stage of adolescence. Second, we examine whether observed changes in self-control ultimately result in meaningful changes in delinquency over time, an extension often overlooked in previous studies (e.g., Burt, Sweeten, and Simons 2014; Hay and Forrest 2006). Third, we examine one hypothesized pathway linking HIs to changes in self-control and subsequent changes in delinquency. In this way, the current study provides a simultaneous examination of both potential sources of influence on delinquency and long-term developmental consequences of HIs on individual differences in rates of change in self-control and delinquency.

The Development of Self-Control

Studies examining Gottfredson and Hirshi's (1990) conceptualization of self-control have typically pointed to various socialization processes as the primary source of between-individual variation, with a significant number of studies identifying parenting practices (Hay and Forrest 2006; Pratt et al. 2004), neighborhood-level influences (Gibson et al. 2010; Pratt et al. 2004), and school-level processes (Burt et al. 2006; Turner et al. 2005) as factors that ultimately shape levels of self-control. Other studies have pointed to genetic and neurobiological processes as important sources of influence (Meijers et al. 2015; Peper et al. 2007; Thompson et al. 2001). Collectively, these two sets of findings seem to indicate that the underlying developmental processes that ultimately contribute to variation in impulsivity are comprised of both biological and social influences (i.e., biosocial). While this observation has been previously recognized (Beaver, Wright, and DeLisi 2007; DeLisi 2015; Hay and Meldrum 2016), not all popular theoretical frameworks organized around the concept of self-control (e.g., Gottfredson and Hirschi 1990; Hirschi 2004) reflect these recent developments.

In line with these observations, the current study makes use of the "dual systems model," a biosocial framework aimed at explaining patterns of self-control over multiple stages of the life course (Harden and Tucker-Drob 2011; Steinberg 2008; Steinberg et al. 2008). The dual systems model posits that imbalance in growth trajectories of two overlapping neurobiological systems ultimately results in lower overall levels of self-control during adolescence. The first neurobiological system, the socioemotional system, is linked to various neural structures that are responsive to emotions, reward, and novelty (Batts 2009; Cardinal et al. 2002; Steinberg 2008). The second system is the cognitive control system and is implicated in various executive functions including decision-making processes, impulse control, and emotional regulation (Batts 2009; Miller and Cohen 2001; Ochsner and Gross 2005). During adolescence, dopamine receptors within the socioemotional system become highly sensitive, providing a rush of dopamine after encountering novel or stimulating experiences, which, in turn, increase overall levels of sensation seeking (Burt et al. 2014; Steinberg et al. 2008). During this same developmental period, the cognitive control system remains relatively immature, and develops at a slower pace, resulting in deficits in executive function during adolescence and marked increases in impulsivity, a lack of inhibition, and the failure to properly evaluate risks and rewards (Steinberg 2010). Based on these developmental patterns, adolescents possess a fully developed socioemotional system and an underdeveloped cognitive control system, resulting in heightened levels of sensation seeking and impulsivity. Importantly, the functional and structural changes to the prefrontal cortex that occur during the transition to adulthood also result in significant increases in executive function including decreases in impulsivity. These changes ultimately result in the ability to curb impulsive behavior and fully evaluate the risk involved in novel, highly stimulating behaviors. In this way, adults may still engage in sensation seeking, but such actions are far less likely to be done impulsively.

Head Injuries as an Environmental Source of Change for Self-Control

The dual systems model also provides a framework that can be used to better understand patterns of delinquency both during and after adolescence. Environmental influences might disrupt normal neurobiological development throughout adolescence and into early adulthood (Fuhrmann, Knoll, and Blakemore 2015). These environmentally triggered neurobiological changes could alter subsequent levels of self-control and ultimately increase risky or delinquent behaviors. This possibility is further underscored by a related line of research that highlights the importance of environmental influences on the development of self-control (Yancey et al. 2013) and changes in self-control over time (Burt et al. 2006). Taken together, these findings seem to indicate that environmental influences that ultimately disrupt normal neurobiological development may also impact subsequent levels of self-control and delinquency. However, relatively few studies have attempted to identify specific environmental sources of long-term, meaningful changes in self-control that fit this particular description.

One environmental influence that may fit this description is HIs. Previous studies reveal four key findings suggesting that HIs may impact self-control and delinquency. First, previous studies have identified structural differences in specific regions of the brain among antisocial populations (Glenn et al. 2010; Meijers et al. 2015; Schug et al. 2010; Yang and Raine 2009). Second, a substantial literature, including multiple meta-analytic reviews, has revealed that HIs are far more prevalent within incarcerated populations (Behnken et al. 2015; Farer and Hedges 2011; Perron et al. 2015; Shiroma, Ferguson, and Pickelsimer 2010). Third, research has indicated that suffering an HI significantly increases the subsequent risk of a wide range of deleterious outcomes including mental health disorders (Sariaslan, Sharp, et al. 2016; Wilk et al. 2012), increases in aggression and anger (Fishbein et al. 2014; Rao et al. 2009), a greater likelihood of recidivism among former inmates (Ray and Richardson 2017), and even premature mortality (Sariaslan, Lichtenstein, et al. 2016). Fourth, studies have revealed that HIs are significantly associated with subsequent deficits in various neurocognitive processes including executive functioning (Dikmen et al. 2009).

Relatedly, previous studies have shown that HIs suffered earlier in the life course can potentially disrupt critical developmental processes that occur during childhood and adolescence (Sariaslan, Lichtenstein, et al. 2016; Yeates et al. 2004). For example, an HI sustained during early adolescence could potentially set into motion a cascade of events that ultimately result in deficits in various executive functions including self-control (Beaver et al. 2007). Directly in line with such observations, a recent study by Fishbein and colleagues (2014) revealed that prison inmates who suffered serious HIs also experienced significant reductions in emotional and cognitive regulation, resulting in increased levels of aggression. Taken together, these findings provide preliminary evidence suggesting that HIs may produce neurobiological deficits that impact self-control and ultimately result in behavioral changes over time.

The Current Study

The current study aims to assess whether HIs sustained prior to adolescence result in greater levels of delinquency through changes in self-control. As outlined previously, a substantial number of studies have found that HIs are associated with subsequent increases in levels of aggression and various forms of antisocial behavior, including violent criminal behavior, even after taking into account a wide range of selection processes. These findings, coupled with results from developmental neuroscience linking self-control to neurobiological development, point to changes in self-control as a possible mechanism through which HIs may affect subsequent engagement in delinquency. We examine this potential mediation process using prospective longitudinal data from a sample of juvenile offenders in the Pathways to Desistance (Pathways) study. The Pathways study was initiated when respondents were in the midst of adolescence (between 14 and 17 years old) and persisted until early adulthood, spanning a total of 7 years. The current study makes use of latent growth curve models (LGCMs), which allow for the examination of between- and within-individual changes in self-control and delinquency over time.

Method

Data

The current study analyzes data from the Pathways study, a prospective longitudinal study carried out over a total of seven years of development (Mulvey 2012). The Pathways is comprised of 1,354 adolescent offenders from Maricopa County, AZ, and Philadelphia, PA (Mulvey et al. 2004). Juvenile offenders between the ages of 14 and 17 at the time of their offense ($M = 16.04$, standard deviation [SD] = 1.14 at the baseline interview) and who were found guilty of a serious offense were eligible to be included in the study (Schubert et al. 2004). In an effort to obtain a more heterogeneous sample, youth adjudicated for a wide range of offenses including both felony and misdemeanor offenses were included in the study. In addition, all youth tried in adult court, and all female offenders were eligible for inclusion. Baseline interviews (time 1 in the current study) began in late 2000 and remained open until early 2003, with new participants added throughout the entire interview period. The resulting sample consisted primarily of male (86.41 percent), African American (41.43 percent), and Hispanic (33.53 percent) youth. After the completion of the baseline interview, participants were interviewed over 10 additional times, spanning a total of seven years. The first six interview periods were carried out over 6-month intervals (6 through 36 months after the baseline interview), and the final four interviews were performed annually (48 through 84 months after the baseline interview). The current study draws from information collected during the baseline interview and each 12-month interval thereafter (12, 24, 36, 48, 60, 72, and 84 months).[1]

The Pathways study contains information on a wide range of concepts directly related to development and the transition from adolescence to adulthood. In addition to the breadth of examined topics, the Pathways team made an explicit effort to repeatedly measure many of the concepts of interest. These unique features of the Pathways study make it a prime resource for investigating longitudinal changes in a wide range of factors directly related to development.

Both the baseline and subsequent interviews were aimed at assessing six domains: background characteristics, individual functioning, psychosocial development and attitudes, family context, personal relationships, and community context (Schubert et al. 2004). Additional information regarding data collection procedures, the content of the interviews, and the main aims of the study has been discussed previously (Mulvey et al. 2004; Schubert et al. 2004).

Measures

Head Injuries. HIs were assessed during each interview using a single, self-reported item in which participants were asked whether they had sustained an HI that caused unconsciousness or required medical attention. During the baseline (time 1) and 12-month through 84-month (times 2-8) interviews, participants were asked whether they had sustained an HI since the date of the previous interview. Responses for each interview were coded dichotomously such that 0 = no and 1 = yes. Descriptive statistics for HI measures and all other study variables are included in Table 1.

Self-control. Self-control was assessed using the impulse control and suppression of aggression subscales from the Weinberger Adjustment Inventory (WAI; Weinberer and Schwartz 1990). The WAI is a standardized assessment of overall socioemotional development and is comprised of 23 items tapping three subscales: impulse control, suppression of aggression, and consideration of others. Additional analyses revealed the impulse control and the suppression of aggression subdomains loaded on a single second-order factor (comparative fit index [CFI] = .95, Tucker–Lewis Index [TLI] = .92, and root mean square error of approximation [RMSEA] = .05). This higher-order construct has been previously defined at *temperance* (Steinberg and Cauffman 1996:252) and represents a relatively broad conceptualization of self-control. The impulse control subscale was assessed using eight items tapping each respondent's ability to control their behavior (e.g., I often say the first thing that comes to my mind without thinking enough about it). The suppression of aggression subscale was comprised of seven items tapping each respondent's ability to control their temper (e.g., People who get me angry better watch out). Participants were asked to rank how closely their behavior over the past six months matched each statement using five response categories ranging from 1 (*false*) to 5 (*true*). Responses to all 15 items were then averaged separately across all waves of data collection (at the baseline interview, $\alpha = .84$) and coded such that higher scores indicate greater levels of self-control.[2] The self-control measure was only included for respondents who provided valid (i.e., nonmissing) responses for at least 12 of the 15 total items, while those respondents with valid responses on fewer than 12 items were coded as missing by the pathways research team. Self-control measures from times 1 through 8 were analyzed, with self-control at time 1 included in the multivariate models as a statistical covariate (described in more detail below).

Delinquency. The Pathways study assessed self-reported offending (SRO) using an adapted version of the popular self-reported delinquency measure developed by Huizinga, Esbensen, and Weiher (1991). The SRO measure was created using 22 items asking respondents how many times they had

Table 1. Descriptive Statistics for All Study Measures.

Study Measures	Mean/Percentage	*SD*	Minimum	Maximum	*N*
Sociodemographic measures (time 1)					
Psychopathy (PCL-YV)	1.51	1.19	0	5	1,354
Intelligence (WASI)	84.52	13.02	55	128	1,342
Exposure to violence	1.57	1.45	0	6	1,351
Socioeconomic status	51.40	12.29	11	77	1,346
Total number of arrests	2.19	2.14	1	15	1,352
Age	16.04	1.14	14	19	1,354
Sex	—	—	0	1	1,354
Male (%)	86.41	—	—	—	1,170
Female (%)	13.59	—	—	—	184
Race	—	—	0	1	1,354
Caucasian (%)	20.24	—	—	—	274
All other races (%)	79.76	—	—	—	1,080
Head injury					
Time 1 (%)	30.35	—	0	1	1,354
Time 2 (%)	3.17	—	0	1	1,260
Time 3 (%)	2.36	—	0	1	1,229
Time 4 (%)	2.76	—	0	1	1,232
Time 5 (%)	3.05	—	0	1	1,214
Time 6 (%)	3.41	—	0	1	1,204
Time 7 (%)	2.29	—	0	1	1,178
Time 8 (%)	2.74	—	0	1	1,131
Self-control					
Time 1	5.61	1.74	1	10	1,351
Time 2	5.92	1.52	1	10	1,260
Time 3	6.11	1.58	1	10	1,229
Time 4	6.14	1.63	1	10	1,232
Time 5	6.45	1.49	1	10	1,213
Time 6	7.01	1.53	1	10	1,204
Time 7	7.23	1.42	1	10	1,179
Time 8	7.21	1.41	1	10	1,131
Aggressive delinquency					
Time 2 (%)	43.97	—	0	1	1,260
Time 3 (%)	34.63	—	0	1	1,230
Time 4 (%)	27.94	—	0	1	1,231
Time 5 (%)	33.91	—	0	1	1,209
Time 6 (%)	32.06	—	0	1	1,201
Time 7 (%)	29.26	—	0	1	1,169
Time 8 (%)	25.75	—	0	1	1,126

(continued)

Table 1. (continued)

Study Measures	Mean/Percentage	*SD*	Minimum	Maximum	*N*
Income delinquency					
Time 2 (%)	27.06	—	0	1	1,260
Time 3 (%)	23.66	—	0	1	1,230
Time 4 (%)	19.50	—	0	1	1,231
Time 5 (%)	25.81	—	0	1	1,209
Time 6 (%)	22.98	—	0	1	1,201
Time 7 (%)	22.41	—	0	1	1,169
Time 8 (%)	19.72	—	0	1	1,126
Overall delinquency					
Time 2 (%)	51.11	—	0	1	1,260
Time 3 (%)	44.55	—	0	1	1,230
Time 4 (%)	38.51	—	0	1	1,231
Time 5 (%)	45.82	—	0	1	1,209
Time 6 (%)	44.05	—	0	1	1,201
Time 7 (%)	40.72	—	0	1	1,169
Time 8 (%)	38.90	—	0	1	1,126

Note: PCL-YV = Psychopathy Checklist—Youth Version; WASI = Wechsler Abbreviated Scale of Intelligence.

engaged in each behavior during the given recall period (which ranged between 6 and 12 months depending on the interview). Responses were summed to tap offending frequency, where larger values indicated greater frequency of offending. Importantly, this offending measure has been used previously in studies analyzing the Pathways data (Loughran et al. 2011; Monahan et al. 2013; Walters 2014). In addition to a general SRO measure, two subscales aimed at providing insight into more specific forms of offending were included. The aggressive offending subscale is comprised of 11 items tapping more violent forms of offending such as getting into a fight, physically beating someone bad enough to require medical attention, and forcing someone to have sexual intercourse. The income offending subscale is comprised of 10 items tapping more financially motivated forms of offending including shoplifting, breaking into a building with the intent to steal something, and using a check or credit card illegally. Descriptive statistics indicated that the three delinquency measures exhibited significant levels of skew at all examined time points (e.g., the *SD* exceeded the mean of each measure). Based on this finding, all three delinquency measures were coded dichotomously, such that 0 = no offenses during the recall period and 1 = one or more offenses during the recall period.[3] In an effort to preserve temporal order, delinquency measures from the baseline interview were excluded from the LGCMs, and only measures collected during the subsequent annual interview periods (times 2–8) were included.

Covariates. A total of 10 statistical covariates were also included in the analyses. First, to isolate the potential impact of HIs suffered prior to the baseline interview and minimize selection bias, HI measures from times 2 to 8 were included in all multivariate models as a time-varying covariate. This process involved regressing the self-control and delinquency measures on the retrospective HI measure from the same time period prior to the estimation of subsequent models, effectively removing any variance explained by the HI measure at each time period. Second, to assess *short-term* changes in self-control (between time 1 and time 2), self-control at time 1 was also included as a covariate. By regressing self-control from time 2 on the same measure from time 1, the resulting coefficients reflect significant *changes* in self-control, as any stability would be captured as covariance between the two measures and effectively controlled in the subsequent models. Third, a measure of psychopathy tapping multiple risk factors associated with delinquency and antisocial behavior including early problem behaviors and callous–unemotional traits was constructed from the Psychopathy Checklist—Youth Version (Forth, Kosson, and Hare 2003). The measure combined 20 items coded on a three-point scale ranging between 0 (*item does not apply to the youth*) and 2 (*item applies to the youth*) during a semistructured interview with a specially trained member of the Pathways team. Scores on all 20 items were summed ($\alpha = .87$) to create an overall measure of psychopathy, with higher scores indicating more psychopathic symptoms.

Fourth, exposure to violence was estimated using the victimization subscale of the Exposure to Violence Inventory (Selner-O'Hagan et al. 1998), which contains six items tapping direct victimization (e.g., Have you ever been chased where you thought you might be seriously hurt?). Respondents were asked to endorse the items they had experienced (0 = *no*, 1 = *yes*), and their responses were summed to reflect the overall number of victimization events each respondent had experienced before time 1. Fifth, based on the previously identified associations involving intelligence, self-control (Boisvert et al. 2013), and antisocial behavior (Schwartz et al. 2015; Ttofi et al. 2016), intelligence was measured at time 1 using the Wechsler Abbreviated Scale of Intelligence (Wechsler 1999) and included in the multivariate models as a covariate. Sixth, each respondent's socioeconomic status (SES) was computed using parental educational attainment and occupational prestige based on Hollingshead's (1971) Index of Social Position and coded such that higher scores indicate higher SES (Mulvey et al. 2004). Seventh, since the pathways data are comprised of a sample of adolescent offenders, a count of total lifetime arrests at the baseline interview was also included. In addition, three demographic covariates—age (measured in years), sex (0 = female, 1 = male), and race (0 = Caucasian, 1 = all other races)—were included in the analyses.

Plan of Analysis

The first step in the analysis estimated a series of LGCMs to examine variability around the latent intercept (i.e., time 2) and latent slope growth factor (i.e., times 2–8) for self-control and the delinquency measures.[4] Significant variation around the intercept at time 2 would suggest that respondents varied in their starting values for each examined concept and significant variation around the slope factor would indicate that respondents demonstrated significantly different trajectories (e.g., increases or decreases) in levels of self-control and delinquency probabilities from time 2 to time 8. Intercept and slope factors were estimated by fixing the seven random intercept factors (times 2–8 measures) to 1 and the time-specific slope factors to 0, 1, 2, 3, 4, 5, and 6, resulting in a model of linear growth. Figure 1 presents a graphical representation of this modeling approach. The resulting models provided an acceptable fit to the data, but nonlinear models (e.g., quadratic and latent basis growth curve models) were also estimated. The results of these supplementary models revealed inferior fit, indicating that linear models provided the closest fit to the data for all examined measures. The fit statistics for the nonlinear models are not presented but are available upon request.

Based on whether significant variation was observed in the intercept and slope factors for the self-control and delinquency measures, the second step in the analysis utilized structural equation modeling (SEM) to examine self-reported HI at time 1 as a predictor of starting levels (time 2) and change (times 2–8) in self-control and delinquency probabilities over time while controlling for covariates. This step was designed to assess whether HIs uniquely predicted subsequent starting levels of self-control as well as starting probabilities and developmental trajectories in delinquent behavior over time. This step of the analysis also involved entering the intercept factor for self-control[5] in a path analysis as an intervening variable between HI at time 1 and the latent intercept and slope factors for delinquency from time 2 to time 8. This step in the analysis focused on examining whether and

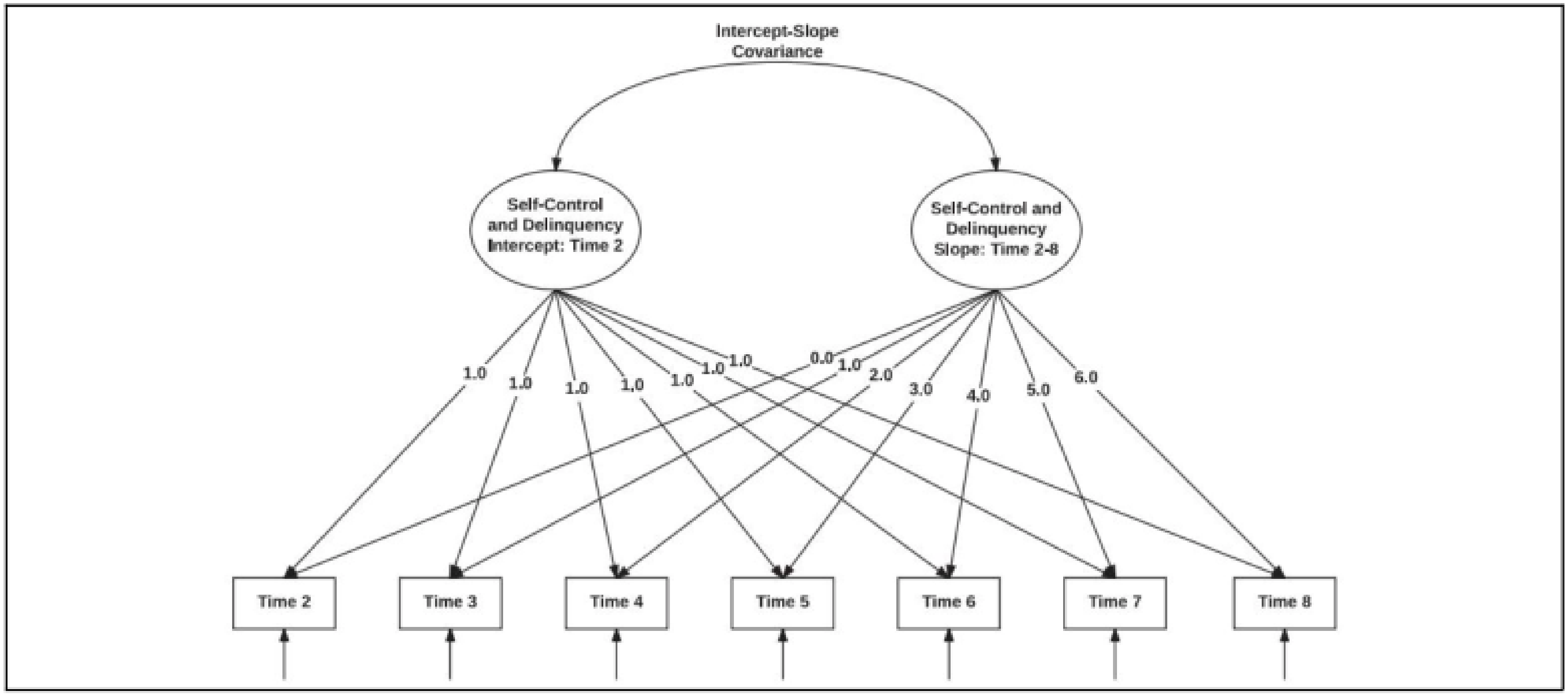

Figure 1. Unconditional Latent Growth Curve Model for Self-Control and Measures of Delinquency.
Notes: Fixed factor loadings represent linear growth for self-control and delinquency from time 2 to time 8. Single headed arrows at the bottom of the figure represent measurement error for each time-specific observed measure of self-control and delinquency. Models included controls for age, sex, and race.

to what extent the association between HIs sustained prior to time 1 and individual differences in starting probabilities and the rate of growth in delinquency from time 2 to time 8 was mediated by changes in self-control from time 1 to time 2.

All SEMs were estimated using M*plus* 7.4 (Muthén and Muthén 1998-2012). For the LGCMs, model fit was evaluated using the CFI, RMSEA, and the standardized root mean square residual (SRMR; Bentler 2007). Based on conventional standards, the following cutoff values were used to evaluate acceptable model fit: CFI $\leq$ .95, RMSEA $\leq$ .06, and SRMR $\leq$ .08 (for a more detailed explanation, see Hu and Bentler 1999). Given the categorical nature of the delinquency measures, missing data were handled using weighted least squares estimation in M*plus* which is based on a modified version of full information maximum likelihood estimation and computes missing values using all available information from observed data and yields estimates similar to other accepted techniques, such as multiple imputation (Acock 2005; H. C. Brown et al. 2008).

Results

Preliminary Analyses

Before examining mean-level trends and individual differences in starting levels and growth in the probability of delinquency, Spearman's rank-order correlations were calculated to assess the degree of stability in self-control and each delinquency measure from time 2 to time 8. Rank-order correlations for self-control ranged between $r^s = .57$ and $r^s = .70$, indicating moderate levels of stability in self-control over time. Respondents demonstrated relatively lower levels of stability in overall delinquency ($r^s = .17$ to $r^s = .38$) and moderate levels of stability in both aggressive ($r^s = .26$ to $rs =$ .34) and income delinquency ($r^s = .29$ to $r^s = .37$) between time 2 and time 8. Additionally, a set of logistic regression models were estimated to describe basic associations between HI at time 1 and delinquency at times 2 through 8. The results, presented in Figure 2, reveal that youth who suffered HIs at time 1 engaged in significantly greater levels of aggressive and overall delinquency at all subsequent time periods. Odds ratios range between 1.37 ($p < .05$, time 8) and 1.71 ($p < .05$, time 2) for aggressive delinquency and between 1.32 ($p < .05$, time 7) and 1.60 ($p < .05$, time 3) for overall delinquency. The relationship between HI and income delinquency was less consistent and only resulted in significant associations at three time points (times 3, 4, and 8).

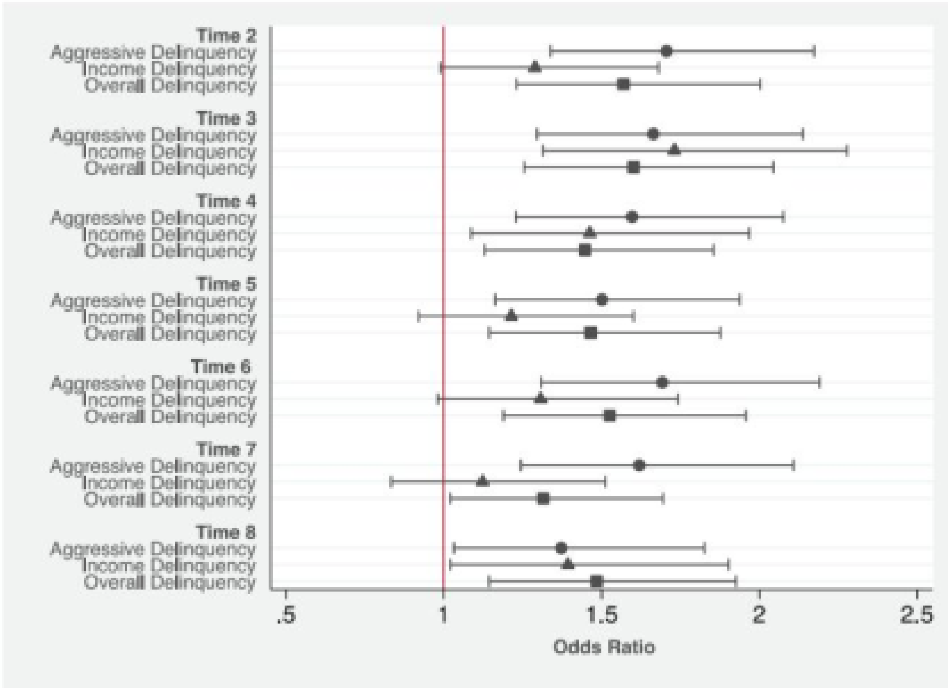

Figure 2. Odds of Delinquency for Youth who Suffered Head Injuries at Time 1.
Notes: Plots present the odds of delinquent behavior after suffering a head injury at each examined time point. Error bars represent 95% confidence intervals and the red line represents an odds ratio of 1. Coefficients with 95% confidence intervals that do not include 1 are considered statistically significant.

Unconditional LGCMs

Table 2 presents results from the unconditional LGCMs. Overall model fit for self-control (CFI = .96, RMSEA = .04, and SRMR = .02), income delinquency (CFI = .95, RMSEA = .04, and SRMR = .03), and overall delinquency (CFI = .95, RMSEA = .04, and SRMR = .04) was good, and model fit for aggressive delinquency was acceptable (CFI = .93, RMSEA = .05, and SRMR = .04). Slope mean parameter estimates indicated that respondents experienced positive gains in self-control ($M = .55$, $p < .001$) and decreases in the probability of aggressive ($M = -.57$, $p < .001$), income ($M = -.17$, $p <$ .001), and overall delinquency ($M = -.28$, $p < .001$) from time 2 to time 8. Models also indicated there was significant variation across individuals in initial levels of self-control (variance = .61, $p < .001$), overall delinquency (variance = .09, $p < .001$), and rates of change in overall delinquency (variance = .18, $p < .001$). The negative standardized covariance coefficients between initial levels and growth in self-control and each of the examined

Table 2. Latent Growth Curve Model Parameter Estimates for Delinquency Measures.

	Self-control		Aggressive Delinquency		Income Delinquency		Overall Delinquency	
Parameter	Estimate	*SE*	Estimate	*SE*	Estimate	*SE*	Estimate	*SE*
Means								
Intercept	5.58	.13	1.43	.07	1.01	.05	1.64	.07
Slope	0.55	.04	−0.57	.09	−0.17	.05	−0.28	.05
Variance								
Intercept	0.61	.01	0.07	.01	0.06	.01	0.09	.01
Slope	0.03	.001	0.21	.001	0.13	.001	0.18	.001
Covariance								
Intercept–slope	−0.19	.04	−0.48	.06	−0.46	.05	−0.42	.06
Residual variance								
Time 2	0.44	.02	0.18	.01	0.14	.01	0.17	.01
Time 3	0.42	.02	0.16	.01	0.12	.01	0.17	.01
Time 4	0.38	.01	0.15	.01	0.11	.01	0.17	.01
Time 5	0.49	.02	0.15	.01	0.14	.01	0.17	.01
Time 6	0.34	.01	0.16	.01	0.12	.01	0.17	.01
Time 7	0.38	.01	0.15	.01	0.11	.01	0.16	.01
Time 8	0.34	.01	0.13	.01	0.09	.01	0.15	.01

Note: Standardized parameter estimates are presented. All models include controls for age, sex, race, and socioeconomic status. *SE* =standard error.
All parameters significant at $p < .001$.

delinquency measures indicated that youth who had higher scores on each measure at time 2 tended to report, on average, lower levels of growth compared to their counterparts. The models also revealed significant individual differences in starting levels and rates of change in self-control ($\text{variance}_{\text{intercept}} = .61$, $p < .001$; $\text{variance}_{\text{slope}} = .03$, $p < .001$) as well as starting probabilities and the rate of change in aggressive delinquency ($\text{variance}_{\text{intercept}} = .07$, $p < .001$; varianceslope $= .21$, $p < .001$) and income delinquency ($\text{variance}_{\text{intercept}} = .06$, $p < .001$; $\text{variance}_{\text{slope}} = .13$, $p < .001$).[6] Taken together, results from the unconditional LGCMs indicate significant individual differences in starting probabilities and rates of change in delinquency.

Path Models

Table 3 presents results from a series of direct and indirect pathway models that examine the association between HI at time 1 and short-term (from time

Table 3. Results from the Saturated Direct and Indirect Pathway Model.

Estimated Paths	Parameter	*SE*	*p*
Bivariate model for self-control and aggressive delinquency			
Direct pathways			
Head injury → self-control$_{intercept}$	−0.08	0.04	0.01
Head injury → aggressive delinquency$_{intercept}$	0.07	0.02	0.01
Head injury → self-control$_{slope}$	−0.03	0.05	0.40
Head injury → aggressive delinquency$_{slope}$	−0.05	0.03	0.01
Self-control$_{intercept}$ → aggressive delinquency$_{slope}$	0.37	0.04	0.00
Indirect pathway			
Head injury → self-control$_{intercept}$ → aggressive delinquency$_{slope}$	−0.04	0.02	0.00
Bivariate model for self-control and income delinquency			
Direct pathways			
Head injury → self-control$_{intercept}$	−0.10	0.02	0.02
Head injury → income delinquency$_{intercept}$	0.03	0.02	0.17
Head injury → self-control$_{slope}$	−0.01	0.01	0.35
Head injury → income delinquency$_{slope}$	−0.01	0.05	0.48
Self-control$_{intercept}$ → income delinquency$_{slope}$	0.28	0.03	0.01
Indirect pathway			
Head injury → self-control$_{intercept}$ → income delinquency$_{slope}$	−0.01	0.05	0.36
Bivariate model for self-control and overall delinquency			
Direct pathways			
Head injury → self-control$_{intercept}$	−0.09	0.02	0.01
Head injury → overall delinquency$_{intercept}$	0.04	0.01	0.05
Head injury → overall control$_{slope}$	−0.02	0.02	0.48
Head injury → overall delinquency$_{slope}$	−0.03	0.02	0.30
Self-control$_{intercept}$ → overall delinquency$_{slope}$	0.34	0.01	0.00
Indirect pathway			
Head injury → self-control$_{intercept}$ → overall delinquency$_{slope}$	−0.02	0.05	0.22

Note: All models included controls for self-control at time 1, psychopathy, intelligence, exposure to violence, socioeconomic status, total number of arrests, age, race, and sex. Head injuries sustained after time 1 were also included in all estimated models as a time-varying covariate. Standardized coefficients are presented.

1 to time 2) and long-term (from time 2 to time 8) changes in self-control as well as starting probabilities and rates of change in delinquency. As can be seen, early HI was associated with initial short-term reductions (i.e., the intercept) in self-control in each of the estimated models (aggressive

delinquency: $\beta = -.08$, $p < .05$; income delinquency: $\beta = -.10$, $p < .05$; and overall delinquency: $\beta = -.09$, $p < .05$). HI was also associated with higher initial levels in aggressive delinquency ($\beta = .07$, $p < .05$) and overall delinquency ($\beta = .04$, $p < .05$). Furthermore, early HI was negatively associated with long-term changes in aggressive delinquency ($\beta = -.05$, $p < .05$), implying that youth who suffered an HI desisted from aggressive delinquency at a slightly faster rate than their peers. HI was not associated with long-term changes (i.e., the latent slope factor) in self-control in any of the examined models, nor was it associated with starting levels ($\beta = .03$, $p = .17$) or long-term changes ($\beta = -.01$, $p = .35$) in income delinquency. The results of the indirect pathway models indicated that short-term changes in self-control significantly mediated the association between HI and long-term changes in aggressive delinquency over time ($\beta = -.04$, $p < .01$). This pathway implies that the association between early HIs and long-term changes in aggressive delinquency is partially mediated by short-term changes in self-control during adolescence, but those individuals that suffered an HI desisted from delinquency at a slightly faster rate compared to their noninjured counterparts. In an effort to provide a more visual representation of these findings, the results for the path model examining aggressive delinquency are presented in Figure 3. The indirect pathway models examining long-term change in income and overall delinquency failed to reveal any significant indirect effects.

Discussion

The recent proliferation of attention surrounding HIs is a welcome trend, given just how often such injuries occur, with approximately 12 percent of adults in the United States having experienced at least one serious HI, and males being twice as likely as females to have suffered an injury (Frost et al. 2013). The prevalence appears to be even greater among delinquent and criminal populations, with rates ranging between 51 percent and 60 percent for incarcerated populations (Farrer and Hedges 2011; Shiroma et al. 2010). Directly in line with these findings, a recent media report revealed that nearly all (approximately 96 percent) inmates housed in the Denver high-risk jail unit experienced at least one serious HI (J. Brown 2015).

Just as troubling are the number of studies linking HIs to a host of negative outcomes including antisocial and criminal behavior (Fishbein et al. 2014; Rao et al. 2009; Ray and Richardson 2017). Despite the presence of an already robust and ever-growing literature, the pathways that ultimately link HIs to behavior remain largely unknown. The current study

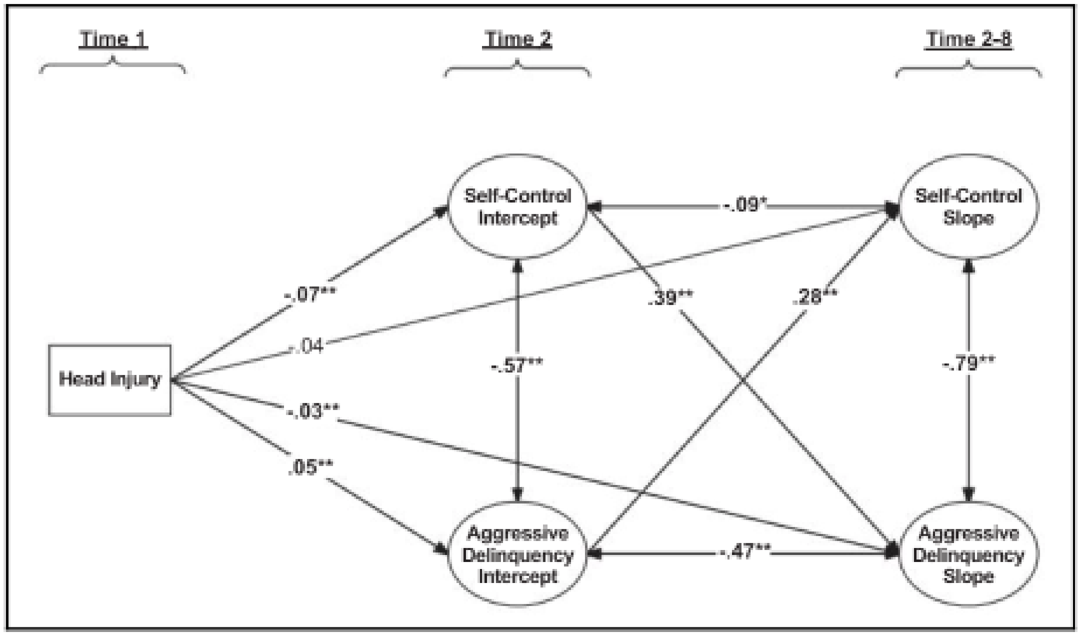

Figure 3. Trimmed Structural Equation Model Examining associations between Head Injury, Self-control, and Delinquency.
Note: Standardized path estimates presented. All paths adjusted for the following covariates: baseline levels of self-control, head injuries that occurred after time 1, psychopathy, intelligence, exposure to violence, SES, total number of arrests, age, sex, and race. Results from indirect pathways: head injury to starting levels of self-control to starting levels in aggressive delinquency (= .09, $p < .001$); head injury to starting levels of self-control to changes in aggressive delinquency (= -.05, $p < .001$). Model Fit: CFI = .98; SMSR = .03; RMSEA = .04.
$^{**}p < .01$; $^{*}p < .05$

aimed to investigate one potential mechanism connecting HIs to delinquency by examining the potential role of self-control. Results from a longitudinal sample of youth from the Pathways data revealed several key findings, all of which warrant additional explanation.

First, the results of the baseline LGCMs revealed that all three measures of delinquency displayed significant levels of stability over the examined time period. While probabilities of the three delinquency measures decreased over time (i.e., indicating desistence patterns), the results of the LGCMs revealed relatively low levels of slope variance, indicating that the majority of the sample displayed similar trajectories of desistance. This finding was somewhat unexpected, but previous studies have identified similar levels of rank-order stability in offending over time (Blokland, Nagin, and Nieuwbeerta 2005; Wiesner, Capaldi, and Kim 2007). Although only speculative, the observed lack of between-individual differences in changes in delinquency may reflect unique characteristics of the Pathways data, which is a high-risk sample of previously adjudicated youth. While the high-risk and homogenous nature of the sample offers many unique advantages, overall variation in delinquency levels and trajectories may be truncated compared to samples drawn from the general population. Future research should explore the observed trends using alternate data sources comprised of heterogeneous youth samples.

Second, the results of the estimated path models revealed that individuals who experienced HIs exhibited significantly greater initial probabilities of aggressive and overall delinquency, while also demonstrating slightly faster decreases in the probability of engaging in aggressive delinquency throughout adolescence and early adulthood. The results of the indirect pathway models produced a similar pattern of findings, wherein short-term changes in self-control following HIs were associated with significantly greater starting levels of overall and aggressive delinquency but slightly faster rates of desistance from aggressive delinquency. These findings suggest that the observed declines in aggressive delinquency may not fully compensate for the more immediate impact of HIs. This possibility appears to be preliminarily supported by the results of the logistic regression models, which revealed that youth who suffered HIs at time 1 engaged in significantly greater levels of aggressive and overall delinquency at all examined time points. However, the LGCM results, which account for potential confounders and selection processes, seem to suggest that HIs in early adolescence are associated with subsequent deficits in self-control and increases in aggressive and overall delinquency in the short-term, but such differences between injured and noninjured youth appear to diminish over time.

Another possibility is that the medical consequences that accompany an HI may prevent future delinquent behaviors.[7] Hospitalization or close monitoring after sustaining an HI might result in blocked future opportunities for delinquent behaviors for some injured youth, which would effectively supplement normative desistance processes already set in motion. This may be especially likely in situations in which youth sustain significant injuries that ultimately result in long-term physical or cognitive disabilities. While injuries of this level of severity are relatively rare among youth (Thurman 2016), the potential impact on behavioral outcomes may be substantial, rendering opportunities for future offending nearly impossible. In this way, the severity of injury may moderate the associations identified in the current study. Future research would benefit from examining this possibility more closely.

The third key finding indicated that HIs were most consistently linked to aggressive delinquency. While the association between suffering an HI and short-term changes in overall delinquency was significant, HIs were not significantly associated with initial levels of income delinquency or long-term changes in income or overall delinquency. This finding is intriguing, particularly in light of previous studies identifying a significant association between sustaining an HI and criminal or delinquent behavior (Fishbein et al. 2014; Perron et al. 2015; Rao et al. 2009; Ray and Richardson 2017). Despite the overall prevalence of this finding, previous research examining the association between HI and offending has largely focused on more descriptive applications (Behnken et al. 2015; Farer and Hedges 2011; Perron et al. 2015; Shiroma et al. 2010) rather than differentiating between various forms of criminal or delinquent behavior. Toward this end, many previous studies have focused on comprehensive indicators of criminal behavior such as arrests. Based on these observations, it remains possible that individuals who suffer an HI are more likely to engage in specialized forms of antisocial behavior such as aggressive delinquency, as is implied by our findings. Future research would benefit from a more thorough examination of this possibility in an attempt to better specify the association between HIs and subsequent behavioral trends.

Another potential explanation for the relatively inconsistent association between HI and delinquency is that the injuries sustained by youth in the Pathways disproportionately impacted the structure or functioning of the frontal lobes, as injuries to this specific brain region have been linked to subsequent increases in aggression (Meijers et al. 2015; Ogilvie et al. 2011). The results of a recent study indicated that individuals who had sustained injuries to a specific region of the frontal lobe (the dorsolateral prefrontal cortex) displayed both greater overall levels of aggression and violence and more positive attitudes toward violence compared to controls (Cristofori et al. 2016). These findings indicate that injuries to specific regions within the frontal lobes may affect underlying beliefs and attitudes related to aggression and violence and, ultimately, aggressive and violent behavior. While the Pathways data do not include information sufficient to identify the specific brain regions impacted by reported injuries, this finding highlights the need for additional research focused on this possibility.

A final possibility is that youth with greater predispositions toward violent and aggressive behaviors may be more likely to select into situations in which HIs are likely to occur. The multivariate SEMs estimated in the current study accounts for some possible sources of selection by including measures of self-control at time 1 and early life behavior problems as statistical covariates. In addition, estimates of differences in self-control and delinquency intercepts and slope trajectories across injured and non-injured youth were adjusted for any subsequent impact of HIs suffered after time 1 by including a dichotomous time-varying covariate in all multivariate SEM models. While these efforts likely dampened the overall effect of selection-based processes on the results, future research would benefit from a more direct examination of whether and how aggressive behavior and low self-control might result in HIs during critical developmental periods.

Despite these contributions to the existing literature, the current study is not without its limitations. First, and perhaps most importantly, the self-reported baseline measure of HI is limited in that it potentially collapses multiple injuries across multiple developmental periods of interest (birth through adolescence) and does not adequately reflect the potential severity of each injury suffered. In addition, it is possible (and likely) that some participants are unaware of HIs suffered early in the life course, resulting in an underreporting of such injuries. Finally, based on data limitations, the amount of time between the sustained HI and self-control at the first examined time point remains undetermined, potentially resulting in artificially deflated associations between HIs and subsequent changes in self-control, as such changes may slowly materialize over time. Future research would benefit from the analysis of data that includes additional information (including timing) on each injury suffered in an effort to provide a more direct evaluation of the extent to which such characteristics potentially impact the pathways involving HI, self-control, and delinquency.

In addition, the observed effect size of HI on both self-control and delinquency was small, raising questions about the substantive significance of HI. There are numerous alternative explanations for the observed small effect sizes. As noted above, several data limitations pertaining to the vague HI measure used in this study may have artificially suppressed observed effect sizes. In addition, truncated variation in starting levels and change in self-control and delinquency due to reliance on a homogenous high-risk sample might have artificially deflated effect sizes. Given the crudeness of the HI measure and the relative homogeneity of the sample, it is notable that short-term and long-term differences in self-control and delinquency emerged across injured and noninjured youth. Furthermore, the observed effect sizes, while small, were robust across a large number of sensitivity analyses. For these reasons, it is quite possible that larger HI effect sizes would emerge in replications using data from a more heterogeneous sample of youth that contain detailed information on the timing and severity of each HI suffered.

The current study was also unable to directly examine neurobiological deficits stemming from HIs. Such an investigation would require combining neuroimaging data with experimental or longitudinal survey measures of self-control and offending but would provide a comprehensive view of the severity and the potential downstream effects of HIs. While previous studies making use of neuroimaging data have identified deficits within various brain regions stemming from HIs (e.g., Scott et al. 2015), such an approach may provide better insight into the mechanisms that connect injuries to short- and long-term psychological and behavioral changes. The current study also relied on a measure of temperance, which represents only two possible facets of self-control. Additional instruments operationalize self-control in a more comprehensive manner, including the Impulsive Behavior Scale (UPPS) (Whiteside and Lynam 2001) and other experimentally based measures such as the Iowa Gambling Task (Bechara, Tranel, and Damasio 2000) or the Game of Dice Task (Brand et al. 2005). In addition, despite the wide range of covariates included the multivariate models, third variable bias is still a concern. Future research would benefit from including additional covariates that were not available in the Pathways, including attention deficit hyperactivity disorder symptoms and medication use, suicidal thoughts and self-injury behaviors, and early effortful control. The current study also relied on survey data from a single informant, which may result in shared methods variance (Campbell and Fiske 1959; Foster and Cone 1995). Future research would benefit from the implementation of multiple informant designs and a direct incorporation of official records data (e.g., arrest records and medical reports). Finally, the Pathways sample is comprised of youth who were found guilty of a serious offense. While this particular feature of the Pathways study addresses a frequent criticism of self-report delinquency surveys (i.e., limited prevalence of serious delinquency in general samples), it also limits the generalizability of the findings from the current study.

Overall, the results of the current study provide preliminary evidence that delinquent behaviors are shaped by a complex network of environmental, biological, and developmental influences. The current study identified a single environmental influence (HIs), operating partly through unmeasured biological processes (neurobiological development and functioning), which influenced changes in self-control and ultimately shaped long-term behavioral patterns. While the results of the current study highlight the importance of HIs, there are likely many other environmental influences that operate through a similar biosocial process to ultimately shape delinquent and criminal behaviors. This observation demonstrates the importance of identifying environmental influences that shape behavioral phenotypes through their influence on biological and developmental processes. The current study provides one clear example of how future research focused on both understanding the etiological development of delinquency and developing effective policy aimed addressing these issues would benefit from a thorough and equal consideration of both biological and environmental influences.

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Notes

1. Additional sensitivity analyses were performed using all available time points. The results did not differ substantively from those reported in the current study. For the sake of clarity, within the context of the current study, the baseline interview is referred to as time 1 and the 12-month through 84-month follow-up interviews are referred to as time 2 through time 8, respectively.
2. The decision to employ a more comprehensive measure of self-control was driven by two related factors. First, previous research linking levels of self-control to developmental patterns of delinquent or antisocial behavior have relied on more comprehensive measures of self-control including the broad conceptualization offered by Gottfredson and Hirschi (1990). Second, a series of supplemental analyses revealed that the impulse control and suppression of aggression subfactors were highly correlated ($r = .96$, $p < .001$) and a single-factor solution (compared to a two-factor solution) provided a superior fit to the data (CFI = .95,

TLI = .92, and RMSEA = .05). Despite these findings, sensitivity analyses were estimated using each subscale separately in an effort to examine the robustness of the findings. The overall pattern of results from the sensitivity analyses were virtually identical to those reported in the current study.

3. Despite significant levels of skew, all of the models were estimated a second time using summed measures of delinquency. While the results of these supplementary models did not differ substantively from the results reported in the current study, models examining the summed delinquency measures resulted in convergence issues and yielded inferior fit statistics. Based on these findings, we decided to dichotomize the delinquency items.
4. The latent growth curve models (LGCMs) use self-control and delinquency measures from times 2 to 8 (i.e., each postbaseline 12-month follow-up interview through month 84) and omit time 1 to maintain temporal order in subsequent models. Specifically, the primary independent variable of interest—HI—is measured at time 1, and while the wording of the question ensures any recorded HIs occurred prior to time 1, the employed delinquency items were retrospective (tapping behaviors over the recall period between interviews). Based on these features of the data, the time 1 measures for self-control and all three forms of delinquency were omitted from the LGCMs, effectively preserving temporal order when examining associations between the time 1 HI measure and the intercept and slope factors for self-control and delinquency. The omission of time 1 measures from the LGCMs also allowed for the examination of short-term changes in self-control by including the time 1 self-control measure in the subsequent path models as a covariate.
5. The current study is more directly concerned with changes in the intercept of self-control (as opposed to the slope) for three reasons. First, based on the dual systems model (Steinberg 2008; Steinberg et al. 2008), our hypotheses expect changes in levels of self-control should precede changes in delinquency, making the intercept the key measure of interest. Importantly, associations involving the HI measure and the intercept factor for self-control represent short-term changes in self-control from time 1 to time 2 since the time 1 self-control measure is included in the estimated models as a covariate (effectively controlling for stability from time 1 to time 2). Second, focusing on changes in both self-control and delinquency over the same time period raises issues regarding temporal order, making it impossible to determine whether changes in self-control contributed to changes in delinquency or vice versa. Third, as discussed in more detail below, overall low levels of variance in the estimated slope factor for self-control indicated minimal changes in self-control over time. Nonetheless, the self-control slope factor was included as an endogenous variable in the estimated models to better isolate the pathways of interest.

6. Since the final analytic sample varied in age (between 14 and 17 at time 1), it is possible that the detected trajectories of delinquency systematically vary by age; for instance, older participants may be at a more progressed stage of the desistance process relative to their younger counterparts. In effort to assess whether multiple trajectories of each of the examined delinquency measures are present within the examined sample, a series of sensitivity models were estimated in which an interaction term between age and the latent slope factor for each delinquency measure was included in the model. A significant interaction term would indicate that variation in changes in the examined delinquency measures significantly varied by age, providing preliminary evidence of multiple developmental trajectories. The results of the sensitivity analysis failed to identify any interaction terms significant at the $p < .05$ level (results not presented but available upon request). Based on these findings, and in the interest of model parsimony, we have omitted the interaction terms from the final analytic models.
7. We would like to thank one of the anonymous reviewers for pointing out this possibility.

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