Head injury, sleep disturbance, and delinquent offending: Evidence from a longitudinal sample of juvenile detainees

Abstract

Research reports that a disproportionate number of juvenile youths report a head injury, and that head injury is associated with reoffending. However, little is currently known about the role of resulting symptoms of head injury that may condition this relationship. One common symptom is sleep disturbance as head injury is argued to damage regions of the brain involved in sleep regulation. The current study analyzes longitudinal data from the Northwestern Juvenile Project (NJP) to: 1) examine associations between head injury and delinquency; 2) assess the moderating role of sleep disturbance, and; 3) test whether associations vary across males and females.

KEYWORDS

delinquency; head injury; Northwestern Juvenile Project; sleep disturbance

1 | INTRODUCTION

It is estimated that close to 7% of children and adolescents below the age of 17 in the United States report ever experiencing symptoms of a concussion, mild traumatic brain injury (mTBI), or traumatic brain injury (TBI) during 2020 (Black & Zablotsky, 2021). Approximately 7.7% of boys report these symptoms, while 5.9% of girls report ever having symptoms of concussion or brain injury. Some of the most common reasons for suffering a head injury (HI) during these early stages of life include running into an object, falling off a moving object, contact from sports involvement or physical violence, and involvement in a car accident (Taylor et al., 2017). It has become apparent that those who are exposed to unsafe environments or engage in risky lifestyles are at risk of suffering a HI before age 17. This conclusion aligns with recent estimates from different countries of the prevalence of HI amongst juvenile justice involved individuals with estimates ranging from 30-80% reporting a HI before the end of adolescence (Corr, 2018; Farrer et al., 2013).

More recent research has begun to examine the association between HI and delinquent offending using longitudinal methodologies and data from adjudicated and at-risk samples of youth. The results from this line of research has been consistent in showing that HI is independently associated with variety scales of delinquency in at-risk and population-based samples (Connolly & McCormick, 2019; Mongilio, 2022) and violent delinquent offending in juvenile samples (Schwartz, 2021). Some studies have even demonstrated that measures of theoretically relevant constructs, such as self-control, partially mediate the link between previous HI and changes in violent offending in samples of predominately male adolescent offenders (Schwartz et al., 2018). Taken together, the collection of evidence from this burgeoning line of research points to a robust connection between HI and engagement in delinquent behavior.

While growing evidence suggests that HI is connected to delinquency, not every child and adolescent who experiences head trauma goes on to engage in delinquent behavior. Much still remains unknown about the conditional role of other factors on this association that may make it more likely that suffering a HI increases the risk of future offending. One factor that is common amongst individuals who suffer a HI - and is a correlate of delinquent offending - is sleep disturbance. Sleep disturbance is defined as encompassing a range of issues from a short sleep-wake cycle to low sleep duration that translates into a lack of physiological rest (Freeman et al., 2020). Victims of HI are theorized to experience short-term and occasionally long-term sleep disturbances as a result of damage to wake-promoting regions of the brain and changes in melatonin secretion. Based on these arguments, it is possible that sleep disturbance may exacerbate the neuropsychological insult of HI on behavioral temperament and externalizing behaviors, such as violent and non-violent delinquency. However, little is known about the role of sleep disturbance on these associations, especially in juvenile justice involved populations, and whether these associations vary across sex as male and female youth commonly report different rates of HI, patterns of sleep, and levels (and forms) of delinquent behavior. The current study aims to begin to address these present gaps in the existing body of research by examining the role of sleep disturbance on within-individual relationships between HI, violent delinquency, and nonviolent delinquency in a sample of previously detained juvenile youth.

2 | HEAD INJURY AND SLEEP DISTURBANCE

One commonly reported side effect of pediatric brain injury is sleep problems (Sheth et al., 2022; Sumpter et al., 2013; Tham et al., 2012). About half of all people who experience a traumatic brain injury (TBI) will suffer from subsequent sleep problems (Aoun et al., 2019), but this estimate is higher for adolescents (Martens et al., 2023). HI-related sleep problems can last

for years, even when other side effects subside (Kaufman et al., 2001; Tham et al., 2012). Research reports that specific HI-related sleep problems can vary from person to person, but usually include trouble falling or staying asleep, experiencing excessive daytime sleepiness, or sleeping more than usual (Aoun et al., 2019; Martens et al., 2023; Weber et al., 2013).

Contemporary research had found that sleep problems are associated with deficits in attention, memory, and judgement, impulse control, aggression, and problem solving (Duclos et al., 2015). One area of the brain specifically suggested to be most affected by poor sleep patterns and responsible for most of these processes is the prefrontal cortex (Dewald et al., 2010; Kamphuis et al., 2012). When the prefrontal cortex is disrupted due to sleep disturbances, individuals are shown to be more likely to engage in risky behaviors as they find it more difficult to make informed decisions and resist emotional impulses (Short & Weber, 2018; Telzer et al., 2014). A robust body of research shows that poor sleep is a risk factor for offending among adolescents, particularly violent acts that are unplanned and reactive in nature (Connolly et al., 2021; Connolly et al., 2022; Semenza & Gentina, 2023). As adolescents do not have a fully mature prefrontal cortex, they are already more prone to engage in delinquency without sleep problems. When sleep problems are experienced, the likelihood of impulsivity, poor decision making, and aggressive behaviors are higher. It has been suggested that sleep problems may even delay or permanently stop full development of the prefrontal cortex (Anastasiades et al., 2022), leading to lifelong cognitive deficits and behavioral difficulties.

Despite the negative effects of poor sleep on cognitive processes in the prefrontal cortex, most people will not physically act out because of poor sleep (Kamphuis et al., 2012). However, specific groups of individuals who have poor prefrontal cortex function to begin with and those who have propensities to engage in aggression, such as juvenile offenders, may be more likely to

experience increased aggression due to insufficient sleep (Kamphuis et al., 2012). As an example, Brown et al. (2023) found that sleep problems were associated with subsequent increases in offending, particularly acts of violent offending, such as robbery and fighting, among a sample of juvenile males. Similarly, Ireland & Culpin (2006) found that adolescent males who were incarcerated and reported poor quality and duration of sleep had higher aggressive tendencies than their peers who reported better sleep patterns.

Head injury-related sleep problems can also affect both boys and girls, but it remains unclear if one sex is affected more than the other. For example, Sheth et al. (2022) found that in a general population, the rates of sleep problems after a HI were similar for boys and girls, while Botchway et al. (2019) reported that male adolescents were more likely to experience sleep problems after sustaining a HI than their female counterparts based on results from 16 studies in which all participants were under age 18. The results of a third study indicated that specific sleep problems following a HI differentially affected community-based male and female adolescents and adults who had recently visited the hospital for a HI (Martens et al., 2023). Specifically, excessive daytime sleepiness was more prevalent in females, whereas poor sleep quality was more prevalent in similar proportions of males and females after a HI. In sum, whether the relationship between HI and sleep disturbance varies across juvenile justice involved males and females remains an open empirical question.

3 | HEAD INJURY, SLEEP DISTURBANCE, AND DELINQUENT OFFENDING

In general, evidence from previous research finds that sustaining a HI is associated with higher levels of offending among juvenile adolescents (Schwartz 2021; Schwartz et al., 2018; Veeh et al., 2018). Two of these studies have used samples of male juvenile offenders from the U.S. and the U.K. and found that HI is associated with a history of elevated violent offending,

general offending, illegal drug use, and past criminal convictions (Huw Williams et al., 2010; Schwartz et al., 2018). The results of a recent third study which analyzed a sample of male juvenile offenders reported that symptoms of post-concussion syndrome, such as irritability and headaches, were predictive of more convictions on a participant's criminal record (Clasby et al., 2020).

Other studies have used samples of male and female juvenile offenders, though the participants in these samples consist predominately of males (Moore et al., 2014; Schwartz, 2021; Schwartz et al., 2017; Veeh et al., 2018). Similar to studies analyzing male offenders, the results of these studies have indicated that participants with a history of HI have higher odds of engaging in general and violent delinquency, including bullying perpetration and fighting (Moore et al., 2014; Schwartz, 2021). For example, Schwartz (2021) found that individual changes in HI were associated with subsequent increased odds of additional violent and general (but not nonviolent) delinquency among participants from the Pathways to Desistance sample. Notably, Schwartz (2021) is currently the only study to the best of our knowledge to include a measure of nonviolent offending. However, none of the existing published studies have evaluated whether the associations between HI and offending vary between males and females.

Historically, the juvenile justice system has primarily consisted of young male offenders (Tracy et al., 2009). As such, it is understandable why past research has been able to analyze mostly male participants. Yet, in recent years, there has been an increase of adolescent female offending and females being processed by the juvenile justice system (Puzzanchera et al., 2022). Despite this increase, currently much remains unknown about whether reported associations between HI and different forms of offending for justice involved male youth apply to justice involved female youth. It is likely that females with a history of HI a more likely to offend than

females without a history of HI. However, females with a history of HI might offend at lower rates than males with s history of HI due to sex differences in developmental trajectories during adolescence. As females have generally better emotional control, less testosterone, and smaller surges in hormones during pubertal development – which has been argued to partially account for the gap in male and female delinquent offending, especially violent offending - it is possible that effect of HI on delinquent behavior may be less prominent in females, or may take on a different shape. Sleep disruptions may also be more strongly associated with violent offending in male adolescents because of the emotional maturity gap that exists between young males and females. In general, girls mature faster than boys, meaning that they report experiencing more positive emotions and are better able to cope with negative experiences compared to males (Chaplin & Aldao, 2013; Zlomke & Hahn, 2010). As such, girls might be better able to handle the cognitive and emotional processes that are adversely affected due to poor sleep. Males on the other hand, may be more prone to engage in offending behavior, particularly reactive violent offending, if they do not have the emotional maturity and coping skills to overcome feelings of impulsivity and aggression. Given these theoretical arguments, there is reason to believe that the effect of poor sleep on violent offending may be more prominent for male adolescents than for female adolescents. It is important to explore possible sex differences that exist to identify appropriate intervention programs for at-risk females. If correlates of offending, including HI, vary between young males and females, then the programs they participate in should also be tailored to their specific needs to help reduce recidivism.

4 | THE CURRENT STUDY

While there has been a growing line of empirical evidence demonstrating a relationship between HI and delinquency, the vast majority of research has not explored the potential role of

theoretically relevant factors related to HI and offending that may exacerbate this association, especially among juvenile justice involved youth. The one exception is Schwartz et al. (2017) in which the authors examined the role of self-control and found that levels of self-control (as measured by eight-item impulse control subscale and the seven-item suppression of aggression subscale of the Weinberger Adjustment Inventory) partially mediated the association between HI and changes in violent. Aside from self-control, another factor that might drive the relationship between HI and offending is sleep disturbance, which has not been explored. As sleep disturbances and HIs can both serve as neuropsychological deficits that can adversely impact emotional and cognitive processes necessary for sufficient self-control and decision making, individuals who experience both simultaneously will likely have a difficult time abstaining from risky and impulsive behaviors. More specifically, adolescents who experience greater sleep disturbances may be more likely to engage in violent and nonviolent offending after experiencing a HI than those who experience fewer or no sleep disturbances. Given that HIs may, but do not always result in sleep disturbances, this is an important area of inquiry as many sleep problems are treatable and can be prevented (Carter et al., 2014).

Another important avenue to explore, which has largely been absent in this line of research focused on at-risk adolescents is how HI may be differentially associated with violent and nonviolent offending. The majority of previous research has tested associations between HI and violent or general offending (which includes measures of both violent and nonviolent offending), but do not include measures of nonviolent offending. Since HI and HI-related sleep disturbance may adversely affect cognitive and emotional processes, it is possible that the likelihood of violent and nonviolent offending will increase as a result. However, the effect of violent offending might be stronger because perpetration of violence is typically the result of

reactive aggression (Kent et al., 2022) and heat of the moment impulses (Krakowski, 2003) that are often the result of poor cognitive and emotional regulation. Indeed, there is limited research which indicates that effect of HI is usually stronger for violent offending than for general (Huw Williams et al., 2010) or nonviolent offending (Schwartz et al., 2017) among at-risk adolescents.

The last gap that the current study aims to begin to address is examining whether and to what extent the association between HI, sleep disturbance, and forms of offending vary across juvenile justice involved males and females. While there are notable differences in the prevalence of HI and rates of offending between males and females (Centers for Disease Control and Prevention, 2018; Nilsson, 2017), differences in the likelihood of sleep disturbance following a HI may affect the relationship differently for males and females. There are a few reasons to suspect this difference. First, female adolescents report more sleep problems and worse overall sleep quality than male adolescents (Baker et al., 2020; Meers et al., 2019). Given that males, overall, report better sleep quality than females, it stands to reason that sudden sleep disturbances, such as those experienced because of a HI, might disproportionally impact males. This is because males, as a group, might not already have healthy ways to cope with sleep disruption. As females experience more sleep disturbances than do males, they likely have ways to deal with these disturbances so that they do not adversely impact behavior. Furthermore, female adolescents are less likely to engage in offending behavior, particularly violent offending, than males (Fagan et al., 2007). Thus, when females do experience increased impulsivity and aggression due to sleep disturbances, they might not alter their regular activities by starting to engage in violent behaviors. Instead, they may take out their aggression in other non-violent ways such as cyber bullying, (Connell et al., 2014).

With this mind, based on findings from contemporary research on HI and delinquency as well as theoretical arguments, we have four testable hypotheses:

H_1: HI is associated with violent delinquent offending.

$H1_A$: The strength of this association is stronger for males than females.

H_2: HI is associated with nonviolent delinquent offending.

$H2_A$: The strength of this association will be similar for males and females.

H_3: Sleep disturbance moderates the association between HI and violent offending whereby greater sleep disturbance strengthens the association between HI and violent delinquency.

$H3_A$: The strength of this moderating effect is stronger for males than females.

H_4: Sleep disturbance moderates the association between HI and nonviolent offending whereby greater sleep disturbance strengthens the association between HI and nonviolent delinquency.

$H4_A$: The strength of this moderating effect is similar for males and females.

5 | METHODS

5.1 | Data

Data for this study came from the Northwestern Juvenile Project (NJP), a longitudinal dataset of 1,829 juvenile detainees between the ages of 10 and 18 from Cook County, Illinois (Teplin, 2013). Participants were recruited for the study as they entered the Cook County Juvenile Temporary Detention Center from 1995 to 1998. Participants were stratified by gender, race, and, and legal status. In total, there are seven waves of NJP data that cover an eight-year period for each participant. Participants were interviewed for the first follow-up wave about three years after baseline. Follow-ups two, three, and four took place every six months thereafter, approximately three-and-a-half to four-and-a-half years after the baseline interview. All baseline

participants were eligible for follow-ups one and four, while a random sample of 997 baseline participants were selected for follow-ups two and three. The purposes of NJP data collection were to study the development and persistence of substance use disorders and mental illness and identifying pathways and patterns of risky behaviors, including offending behaviors over time, from adolescence though young adulthood. This study uses NJP data from the baseline interviews as well as from the first four follow-up waves.

5.2 | Measures

Head Injury (HI). HI was assessed during each follow-up wave by asking participants if they had sustained an HI since the data of their last interview. Responses for each measure of HI were coded dichotomously in which 0 = no and 1 = yes. Table 1 presents the descriptive statistics for the HI measures and all other variables included in the present study. As can be seen, around 20% of respondents reported sustaining a HI after the baseline at Wave 1. Approximately 7% of respondents reported sustaining a new HI at waves 2 and 3 and 23% of respondents reported sustaining a new HI at wave 4.

Insert Table 1 About Here

Sleep Disturbance. Sleep disturbance was assessed during each follow-up wave using three self-report questions. Participants were asked if they were sleepy during the day a lot, had a regular bedtime, and usually felt like they had enough sleep during the last two weeks. Responses for each measure were coded dichotomously in which 0 = no and 1 = yes. The last two measures were reverse coded. Responses to all questions were summed together to create an overall measure of sleep disturbance at each follow-up wave with higher scores indicating higher levels of sleep disturbance (range = 0-3).

Violent Offending. Violent offending was measured at each follow-up wave using four self-report questions. Participants were asked to answer how many times they: used a gun, attacked someone with a weapon with the idea of seriously hurting them, beat someone up with the idea of seriously injuring them, and stalked, kidnapped, and/or abducted someone since the last interview. Responses for each measure of violent offending were coded dichotomously in which 0 = zero times and 1 = one or more times. Responses to all questions were summed together to capture the variety and frequency of violent offending at each follow-up wave with higher scores indicating greater offending (range = 0-4). The reliability of all measures was adequate (Kuder Richardson coefficients = .67-.73).

Nonviolent Offending. Nonviolent offending was measured at each follow-up wave using two items. Participants were asked to answer how many times they: stole something and sold drugs since the last interview. Responses for both measures of nonviolent offending were coded dichotomously in which 0 = zero times and 1 = one or more times. Responses to all questions were summed to capture the frequency of nonviolent offending at each follow-up wave. Higher scores indicate greater frequency of nonviolent offending, and scores range from 0-2. The reliability of these measures was adequate based on the number of items used to capture nonviolent offending (Kuder Richardson coefficients = .58-.66).

Predictor Variables. Several variables were included in the analyses as predictors of between-individual differences that could be related to HI and offending over time. These include a measure of HI, psychological, sexual, and physical abuse, school enrollment, and number of days previously in spent detention. HIs experienced before the baseline interview was measured by a dichotomous variable indicating if participants ever had a HI at baseline (0 = no, 1 = yes). We also include a measure of psychological abuse which was assessed by combining responses from

four items asking respondents about their history with psychological victimization from parents and guardians including being made fun of. Sexual abuse was comprised of responses from five items tapping each respondent's history of unwanted sexual advances from adults in their lives. Physical abuse was comprised of six items tapping each respondent's history of physical victimization from parents and guardians including being hit very hard, beaten, and kicked. For each measure of abuse, higher scores indicate greater history of abuse. School enrollment is a dichotomous measure which indicates if participants were enrolled in school at baseline (0 = no, 1 = yes). Lastly, we include a continuous variable controlling for how many days participants previously spent in detention at the baseline interview.

Demographic Predictors. A total of four demographic predictors of between-individual differences in HI and offending were included in the analyses, all of which were measured at baseline. These measures include age, race, gender, and intelligence. Age is a continuous measure that is measured in years. Race consists of three binary measures indicating if participants are Black/African American (= 1), Hispanic (= 1), or belong to another racial category (= 1), with White as the reference category for each variable (= 0). Sex is a dichotomous measure with male (= 0) and female (= 1) being the two options. Intelligence was estimated using participant's scores from the Peabody Picture Vocabulary Test, which is designed to measure verbal aptitude (Dunn & Dunn, 1997) and is correlated highly with IQ (Hodapp & Gerken, 1999).

5.3 | Plan of Analysis

The analysis for the current study proceeded in a series of linked steps. First, bivariate associations between HI, violent offending, nonviolent offending, and sleep disturbance from Wave 1 to Wave 4 were assessed. Based on the distributional properties of the variables,

tetrachoric (i.e., appropriate for two binary variables), and polychoric (i.e., appropriate for a binary and categorical variable as well as two categorical variables) correlation coefficients were calculated. The results from this first stage of the analysis will help to provide preliminary evidence of the strength and direction of relations between key variables at the same time and over time. Second, a random intercept cross-lagged panel model (RI-CLPM) was fit to the data to examine bidirectional associations between within-individual changes in HI, violent offending, and nonviolent offending from Waves 1 to 4. This approach was used over the traditional autoregressive cross-lagged model approach (CLPM), which only allows for between-individual estimation of bidirectional effects between repeated measures. The RI-CLPM includes both a between-individual component that captures stable between-person differences and a within-individual component that captures within-person changes and relations between variables over time (Mulder & Hamaker, 2020). As such, the between-individual component is estimated to account for stable (or time-invariant) differences between respondents for HI and different forms of offending, while the within-individual components control for within-individual autoregressive (i.e., carry over) effects from one time point to the next and within-individual concurrent covariances (i.e. same time) between HI and offending (Hamaker et al., 2015; Mulder & Hamaker, 2021).

Based on the results from the second step of the analysis, the third and final step focused on examining whether sleep disturbance moderated any observed longitudinal within-individual cross-lagged paths between HI, violent offending, and nonviolent offending for males and females. To assure temporal order and align with theoretical expectations, within-individual deviations in sleep disturbance was included as a moderator from the same wave as HI. Moderation was tested by creating an interaction term between a within-individual deviation

component of sleep disturbance on the regression cross-path from within-individual deviation in the likelihood of HI to within-individual deviation in offending (Ozkok et al., 2022). Figure 1 presents the RI-CLPM for HI and offending from Wave 1 to Wave 4 with moderation by sleep disturbance that was tested in the current study. As presented, all factor loadings are fixed to '1' with covariances between within-individual components at Wave 1 fixed to '0' and random intercepts fixed to '0' for estimation purposes (Mulder & Hamaker, 2021). All RI-CLPM and CLPM models were estimated using M*plus* version 8.4 (Muthén & Muthén, 2019) with the default WLMSV estimator and the DIFFTEST option to obtain a chi-square difference test. Moderation as tested under the 'DEFINE' common section with the "*" option between within-individual components (Stride et al., 2015). Model fit was evaluated to assess whether the RI-CLPM provided a better fit to the data compared to CLPM for each association. The evaluation of model fit was based on values from the Comparative Fit Index (CFI), Root Mean Square Error of Approximation (RMSEA), Standardized Root Mean Square Residual (SRMR), and chi-square statistic (χ^2). In line with previous recommendations (Hu & Bentler, 1999), the follow cut-off values were used to indicate good model fit: CFI $\geq$ .95; RMSEA $\leq$ .05; SRMR < .08; and a nonsignificant (p > .05) model χ^2 statistic. A Santorra-Bentler scaled χ^2 difference test (Santorra & Bentler, 2001) was also used to compare nested models.

Insert Figure 1 About Here

6 | RESULTS

Table 2 presents the correlation coefficients between all key variables. Coefficient estimates for females are presented above the diagonal, while coefficient estimates for males are presented below the diagonal. As can be seen, there was moderate stability in HI, violent delinquency, and nonviolent delinquency for both males and females with associations stronger

among males than females. HI was contemporaneously associated with both forms of delinquent behavior and temporally associated with both across all waves except for Wave 1 HI and Wave 4 nonviolent delinquency for males and females. These results offer preliminary evidence of significant bivariate relations between key variables from Wave 1 to Wave 4 that are the focus of the primary analysis.

Insert Table 2 About Here

Table 3 presents model fit information for the unconditional RI-CLPMs and CLPMs for violent and non-violent delinquency where time invariance constraints were included and excluded to evaluate consistency of measurement across the study period. Model fit indices showed that the RI-CLPM (Model 4) with measurement invariance of head injury provided the best fit to the data for both forms of delinquent offending. Model fit information for the final RI-CLPM with all predictors of between-individual differences for HI and offending (i.e., random intercepts) was reported at the bottom of each comparison analysis. Based on these results, RI-CLPMs were chosen over CLPMs for the analysis.

Insert Table 3 About Here

Figure 2 presents all significant parameter estimates from the final RI-CLPM for HI and violent offending for males. As can be seen, the random intercept components for HI and violent delinquency were significantly and positively correlated indicating that between-individual differences for risk of HI from Wave 1 to Wave 4 was associated with between-individual differences in violent offending. Male participants with a history of ever having a HI and higher levels of reported physical abuse were more likely to demonstrate a higher likelihood of suffering a HI over time compared to those without a history of a HI and lower levels of physical abuse, while participants with higher levels of reported sexual abuse were more likely to

demonstrate higher levels of violent offending. There was also significant within-individual auto-regressive associations from HI at Wave 1 to HI at Wave 2 (β = .35, 95% CI = .26-.42) and Wave 3 to Wave 4 (β = .19, 95% CI = .10-.28) suggesting that within-individual deviations in likelihood of HI at one wave was positively associated with temporal within-individual deviations in likelihood of HI at a subsequent wave. The results also showed significant cross-lagged associations between HI at Wave 1 and violent offending at Wave 2 (β = .20, 95% CI = .16-.28) and HI at Wave 3 with violent offending at Wave 4 (β = .25, 95% CI = .19-.31). Lastly, moderation analyses from the model demonstrated that within-individual deviation in sleep disturbance at Wave 1 moderated the cross-path from HI and Wave 1 to violent delinquency at Wave 2 (β = .06, 95% CI = .03-.10) suggesting that cross-path effect was stronger at higher levels of sleep disturbance. A similar pattern was found for the cross-path from HI at Wave 3 to violent delinquency at Wave 4 (β = .10, 95% CI = .05-.12).

Insert Figure 2 About Here

Figure 3 presents the results from the final RI-CLPM for HI and violent delinquency for females. The random intercept components were positively correlated suggesting that females who demonstrated a higher likelihood of HI from Wave 1 to Wave 4 also reported, on average, higher levels of violent offending. Reports of ever having a HI early in life was positively associated with between-individual differences in likelihood of HI over time and higher levels of sexual abuse were associated with, on average, higher levels of violent offending. While weaker effects than observed among male participants, within-individual deviations in the likelihood of HI at Wave 1 for females was associated with within-individual deviations in violent offending at Wave 2 (β = .16, 95% CI = .07-.25) and HI at Wave 2 with violent offending at Wave 3 (β =

.15, 95% CI = .05-.22). Sleep disturbance was not found to moderate any of these cross-path associations (*p*s > .05).

Insert Figure 3 About Here

Figure 4 presents all significant parameter estimates from the final RI-CLPM for HI and nonviolent offending for males. The random intercept components for HI and nonviolent offending were significantly and positively correlated signifying that between-individual differences for risk of HI from Wave 1 to Wave 4 was associated with between-individual differences in violent offending. Higher levels of physical abuse were also associated with higher levels of nonviolent offending. On average, males who reported sustaining an early HI were more likely to report additional HIs compared to males who did not report sustaining an early HI. However, there were no significant within-individual auto-regressive associations between HI and nonviolent offending, suggesting that within-individual deviations in likelihood of HI at any given wave was not associated with temporal within-individual deviations in likelihood of nonviolent offending at a subsequent wave. As we did not find evidence of significant cross-lagged paths, moderation analyses were not conducted.

Insert Figure 4 About Here

Figure 5 presents the significant parameters from the final model for HI and nonviolent offending among females. The random intercept components were positively correlated suggesting that females who demonstrated a higher likelihood of HI from Wave 1 to Wave 4 also reported higher levels of nonviolent offending, on average. Female participants with a history of ever having an early HI were more likely to demonstrate a higher likelihood of suffering a HI over time compared to those without a history of early HI. Higher levels of reported sexual abuse and being enrolled in school at baseline were positively associated with between-individual

differences in likelihood of nonviolent offending over time. Similar to results for males, there were no significant within-individual auto-regressive associations between HI and nonviolent offending among females, indicating that within-individual changes in likelihood of HI at any given time point was not associated with within-individual deviations in likelihood of nonviolent offending at a subsequent wave. Since we did not find evidence of significant cross-lagged paths, moderation analyses were not conducted.

Insert Figure 5 About Here

7 | DISCUSSION

Recently, a growing body of research has demonstrated that HI is associated with subsequent offending, particularly violent offending in juvenile justice involved youth (Schwartz 2021; Schwartz et al., 2018; Veeh et al., 2018). Yet, there are still several questions regarding: 1) the potential role of theoretically relevant factors on this association over time, such as sleep disturbance; 2) whether sleep disturbance differentially conditions the relationship between HI and different forms of delinquent offending, and; 3) if these associations are observed among justice involved females as most reported findings are based on either all male, or mostly male samples. Given the rise in the number of females entering the juvenile justice system in recent years (Puzzanchera et al., 2022), it is important to examine the strength of these associations to assess if they are replicated in adolescent females. The current study began to address these gaps in this line of research by examining how changes in HI are associated with changes in violent and nonviolent offending and the role that sleep disturbances play in these relationships across male and female juvenile adolescents who were previously detained. The results of our analyses revealed three key findings that warrant further discussion.

First, within-individual changes in HI were associated with subsequent within-individual changes in violent delinquency in both males and females, albeit at different waves. This provides support for Hypothesis 1 and suggests that sustaining a HI is uniquely related to cognitive and emotional processes associated with the perpetration of violence, such as reactive aggression (Kent et al., 2022). Further, as predicted, these crossed lagged paths were stronger for males than for females, indicating that the effect of HI on violent offending affects males more strongly than females. This finding could be attributed to sex differences in developmental trajectories during adolescence as females have generally better emotional control, less testosterone, and smaller surges in hormones during puberty which are associated with reduced violent offending.

Second, after taking into account between-individual differences (i.e., rank-order stability) in HI and non-violent delinquency, HI was associated with non-violent offending contemporaneously, but was not associated with within-individual changes among male participants. A similar pattern was found for female participants where HI was associated with non-violent offending at the same time, but no cross-lagged associations were found. These findings offer partial support for Hypothesis 2 suggesting that HI is associated with concurrent nonviolent offending similarly for males and females, but not across time, offering limited evidence that would align with causal inference. As our results suggest that sustaining a HI is associated with subsequent changes in violent, but not nonviolent offending, future research should aim to replicate these findings and untangle possible reasons that could explain these differences. For example, HI might impact the developmental pathways associated with reactive aggression, which tends to be a prominent factor in violent offending, but HI might not affect the

developmental pathways associated with proactive aggression, which is more often a factor in nonviolent offending (Kent et al., 2022).

Third, within-individual deviations in sleep disturbance was found to moderate associations between within-individual cross-lagged paths between HI and violent offending for males, but not females, offering mixed support for Hypothesis 3. One possible explanation for these results is that females reach emotional maturity earlier than males and thus might be better able to cope with the emotional processes that are adversely affected due to poor sleep compared to males (Chaplin & Aldao, 2013; Zlomke & Hahn, 2010). Another potential explanation for why poor sleep was found to moderate the associations between within-individual deviations in HI and changes in violent offending for males, but not females might be related to the fact that males generally report better sleep quality than females (Baker et al., 2020; Meers et al., 2019). As such, females might already have healthy ways to cope with sleep disturbances so that they do not adversely impact behavior whereas males might not, resulting in poor sleep playing a larger role in violent offending among males but not females.

As the current findings suggest that the mechanisms that drive the relationship between HI and violent offending are different for male and female adolescents, future research would benefit from identifying additional factors that may explain this relationship in females such as peer influences or mental health symptomatology. By identifying these mechanisms, juvenile justice policy makers will be able to implement more effective programs for delinquency intervention for females. If there are sex differences in factors associated with offending, then programs aimed at reducing offending should be differentiated by sex, or even better, individualized to the specific juvenile youth. For example, as males might be more likely to violently offend due to poor sleep, there should be an emphasis on teaching them about better

sleep practices. However, if research finds that females are driven to offend violently because of negative peer influences, then they should be taught ways to cope with peer pressure.

The reported findings have important implications for head injury detection and treatment. Namely, there needs to be improved access to healthcare for at-risk adolescents whose families might not be able to afford it currently. Over two-thirds of adolescents in juvenile detention facilities have health problems that have been neglected (Acoca et al., 2014), which indicates a widespread problem concerning healthcare access. As improving healthcare access and costs is difficult and might take several years to accomplish, a simpler policy would be to assess for HI symptoms during intake into juvenile facilities and treat symptoms as needed. The findings presented in the current study also highlight implications for intervention programs targeted for at-risk adolescents. More specifically, because results indicate that the mechanisms driving the relationship between HI and offending differ among males and females, and that past research suggests females offend for different reasons than males (Chan et al., 2021; Hart et al., 2007), programs should be both gender-specific and individualized to the participant.

While the findings of this study expand on the current body of knowledge on the associations between HI and adolescent offending, this study does present some notable limitations that should be addressed in future research. First, the measures of interest (HI, sleep disturbance, and both forms of offending) analyzed in this study were all self-reported by the participants as they were entering a juvenile detention facility. As such, and even though the participants were being interviewed by trained professionals, there might be errors in the participants' responses due to falsification, inability to remember certain events, or inability to correctly comprehend and respond to the questions being posed. Second, due to the nature of working with secondary data, we did not have a measure of HI severity. Some previous studies

have found that severe HIs are more strongly associated with offending than minor HIs (McKinlay et al., 2014). In the future, efforts should be made to assess the severity of HIs sustained by participants during primary data collection. Third, as our measure of nonviolent offending only consisted of responses to two items (number of times stolen something and sold drugs), there are several facets of nonviolent offending that we were unable to capture, such as property damage. This might, in part, explain some of the observed nonsignificant findings between HI and nonviolent offending. Future research should include a more comprehensive index of nonviolent offending to offer a more complete picture regarding the association between HI and nonviolent offending.

8 | CONCLUSION

The findings from the current study indicate that within-individual changes in HI are associated with within-individual changes in violent, but not necessarily nonviolent delinquent behavior among juvenile justice involved males and females. Sleep disturbance may serve as a conditioning factor for this association whereby the effect of HI on violent offending is stronger at higher levels of poor sleep in males but not in females, suggesting that the mechanisms driving this relationship are different across sex. Based on the reported results as well as the findings from past studies highlighting differences between male and female offending, delinquency intervention programs for juvenile adolescents should be targeted based on sex, especially as the number of females involved in the juvenile justice system has risen over time. To get a more comprehensive understanding of the nuances of the relations between HI and adolescent offending, future studies should examine how HI severity influences a multitude of violent and nonviolent offences in adolescent males and females.

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TABLE 1 Descriptive statistics

	Mean/%	SD/n	Min	Max	N
Head Injury $_{\text{Wave 1}}$	19.66%	321	0	1	1,633
Head Injury $_{\text{Wave 2}}$	7.01%	64	0	1	913
Head Injury $_{\text{Wave 3}}$	6.79%	61	0	1	898
Head Injury $_{\text{Wave 4}}$	23.00%	371	0	1	1,603
Violent Offending $_{\text{Wave 1}}$	1.47	1.17	0	4	1,653
Violent Offending $_{\text{Wave 2}}$	.45	.80	0	4	919
Violent Offending $_{\text{Wave 3}}$	.42	.77	0	4	894
Violent Offending $_{\text{Wave 4}}$	.57	.89	0	4	1,606
Nonviolent Offending $_{\text{Wave 1}}$	.99	.78	0	2	1,671
Nonviolent Offending $_{\text{Wave 2}}$	.29	.55	0	2	922
Nonviolent Offending $_{\text{Wave 3}}$	.26	.50	0	2	902
Nonviolent Offending $_{\text{Wave 4}}$	.39	.61	0	2	1,607
Sleep Disturbance $_{\text{Wave 1}}$	1.56	.99	0	3	1,542
Sleep Disturbance $_{\text{Wave 2}}$	1.66	1.00	0	3	864
Sleep Disturbance $_{\text{Wave 3}}$	1.62	.98	0	3	853
Sleep Disturbance $_{\text{Wave 4}}$	1.59	1.01	0	3	1,519
Ever Head Injury $_{\text{Baseline}}$	45.75%	797	0	1	1,742
Psychological Abuse	8.05	6.11	0	24	1,728
Physical Abuse	8.88	7.38	0	31	1,322
Sexual Abuse	.11	.36	0	3	1,729
School Enrollment $_{\text{Baseline}}$	71.08%	1,295	0	1	1,822
PPVT Baseline	72.14	16.51	19	125	1,602
Days in Detention $_{\text{Baseline}}$	24.60	77.66	0	1,277	1,683
Age $_{\text{Baseline}}$	14.90	1.39	10	19	1,653
Race					
Black/African American	54.94%	1,005	-	-	1,829
White/Caucasian	16.18%	296	-	-	1,829
Hispanic	28.64%	524	-	-	1,829
Other	.02%	4	-	-	1,829
Sex					
Male	64.07%	1,172	-	-	1,829
Female	35.92%	657	-	-	1,829

TABLE 2 Bivariate correlations

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16.
1. Head Injury Wave 1	-	.21***	.17**	.12*	.23***	.17**	.14**	.08*	.11*	.10*	.07*	.03	.11*	.09*	.05	.01
2. Head Injury Wave 2	.37***	-	.30***	.18**	.12**	.23***	.16**	.15**	.10*	.10*	.08*	.07*	.09*	.14**	.14**	.11**
3. Head Injury Wave 3	.20***	.35**	-	.29***	.11*	.18**	.27***	.18**	.03	.07*	.13**	.18**	.06	.13**	.15**	.12**
4. Head Injury Wave 4	.16***	.24**	.32**	-	.04	.13**	.17**	.28***	.30***	.07*	.09*	.11**	.02	.07*	.10*	.14**
5. Violent Offending Wave 1	.28***	.15**	.14**	.07*	-	.27***	.27***	.25***	.49***	.35***	.31***	.27***	.15**	.11*	.08*	.02
6. Violent Offending Wave 2	.21***	.29***	.20***	.15**	.39***	-	.33***	.27***	.24***	.38***	.32***	.28***	.13**	.18***	.10*	.08*
7. Violent Offending Wave 3	.13**	.23***	.30***	.21***	.32***	.36***	-	.31***	.27***	.28***	.35***	.31***	.04	.14**	.16**	.10*
8. Violent Offending Wave 4	.10*	.17**	.23***	.31***	.29***	.33***	.40***	-	.23***	.33***	.36***	.42***	.03	.11*	.16**	.18**
9. Nonviolent Offending Wave 1	.16**	.14**	.05	.05	.56***	.29***	.31***	.29***	-	.35***	.33***	.31***	.12**	.08*	.04	.02
10. Nonviolent Offending Wave 2	.11*	.17**	.09*	.08*	.45***	.46***	.33***	.34***	.43***	-	.37***	.29***	.10*	.18**	.10*	.01
11. Nonviolent Offending Wave 3	.10*	.13**	.14**	.10*	.33***	.39***	.41***	.41***	.37***	.45***	-	.34***	.02	.12*	.15**	.09*
12. Nonviolent Offending Wave 4	.06	.08*	.17**	.12**	.30***	.38***	.38***	.47***	.28***	.35***	.43***	-	.03	.02	.10*	.13*
13. Sleep Disturbance Wave 1	.14**	.07*	.08*	.06	.18***	.17**	.05	.06	.14**	.13*	.04	.01	-	.41***	.36***	.32***
14. Sleep Disturbance Wave 2	.11**	.12**	.11**	.07*	.14**	.19***	.12**	.10*	.10*	.17**	.10*	.03	.47***	-	.40***	.33***
15. Sleep Disturbance Wave 3	.09*	.14**	.15**	.12**	.10*	.13**	.18**	.14**	.07*	.12*	.16**	.08*	.38***	.49***	-	.46***
16. Sleep Disturbance Wave 4	.07*	.09*	.10*	.15**	.05	.09*	.13**	.19***	.02	.04	.08*	.11**	.31***	.36***	.52***	-

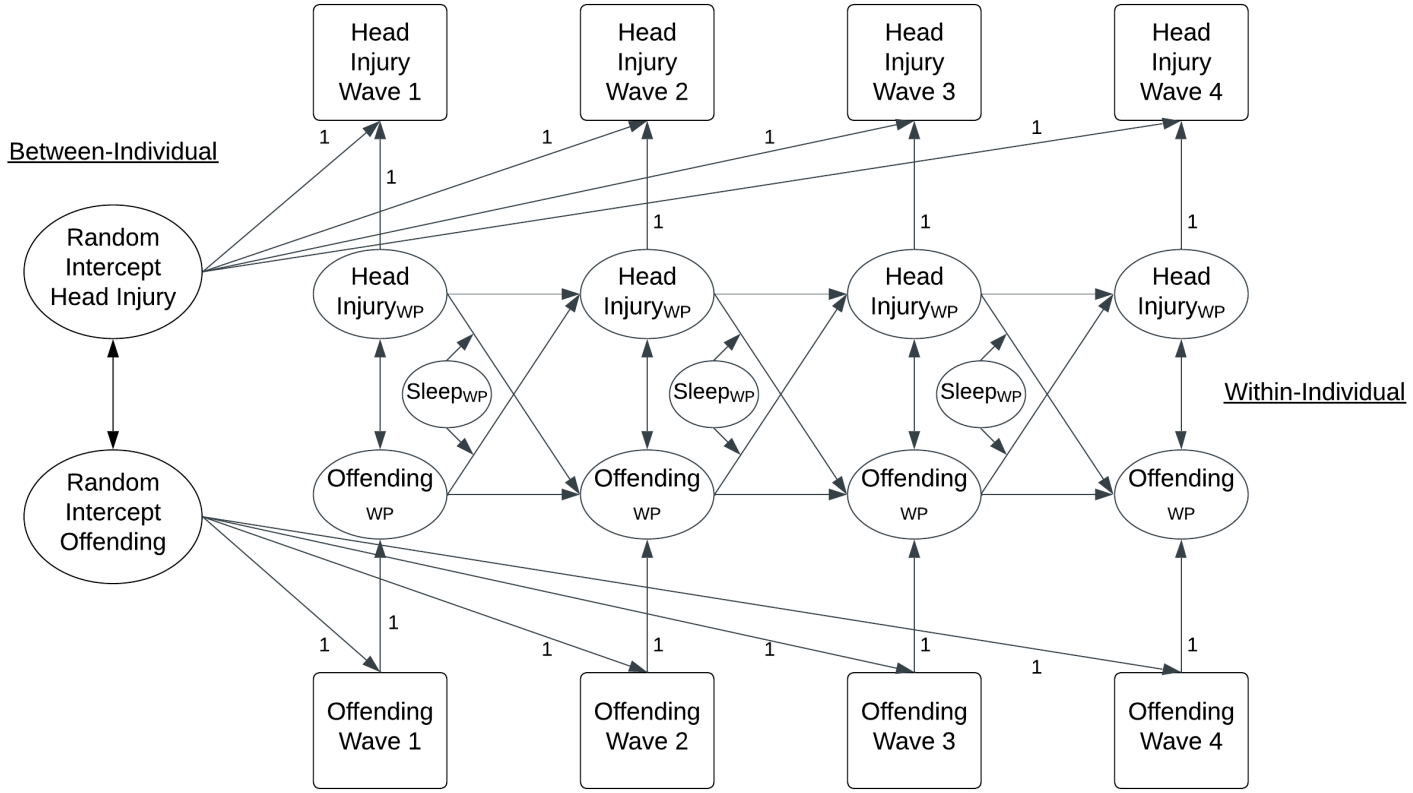
Notes: Polychoric correlation coefficients presented for females above diagonal and polychoric correlation coefficients for males presented below diagonal. *** $p < .001$; ** $p < .01$; * $p < .05$.

TABLE 3 Model fit for cross-lagged panel models vs. random-intercept cross-lagged panel models for head injury and offending

Model	MLR $\chi 2$ (*df*)	CFI	RMSEA	SRMR	SB $\chi 2$ (*df*)	Decision
Violent Delinquency						
1. RI-CLPM, unconditional without time invariance constraints	52.08 (26) *p*=.064	.947	.042	.059	-	-
2. CLPM, unconditional model without time invariance constraints	97.15 (29) *p*=.000	.771	.083	.102	29.51 (4) *p*=.000	Model 2 rejected
3. RI-CLPM, unconditional model with time-invariance of head injury and violent offending	75.96 (34) *p*=.003	.853	.061	.071	36.42 (11) *p*=.000	Model 3 rejected
4. RI-CLPM, unconditional model with time-invariance of only head injury	56.24 (31) *p*=.059	.957	.040	.053	9.84 (6) *p*=.126	Model 4 retained
5. RI-CLPM, final model with time-invariance of only head injury and predictors of random intercepts (between-individual)	78.56 (63) *p*=.017	.922	.043	.059	-	-
Nonviolent Delinquency						
1. RI-CLPM, unconditional without time invariance constraints	56.41 (26) *p*=.070	.931	.048	.060	-	-
2. CLPM, unconditional model without time invariance constraints	101.06 (29) *p*=.000	.753	.087	.113	31.73 (4) *p*=.000	Model 2 rejected
3. RI-CLPM, unconditional model with time-invariance of head injury and nonviolent offending	79.42 (34) *p*=.001	.839	.068	.073	39.21 (11) *p*=.000	Model 3 rejected
4. RI-CLPM, unconditional model with time-invariance of only head injury	59.75 (31) *p*=.062	.962	.039	.051	11.54 (6) *p*=.176	Model 4 retained
5. RI-CLPM, final model with time-invariance of only head injury and predictors of random intercepts (between-individual)	80.41 (63) *p*=.022	.914	.052	.063	-	-

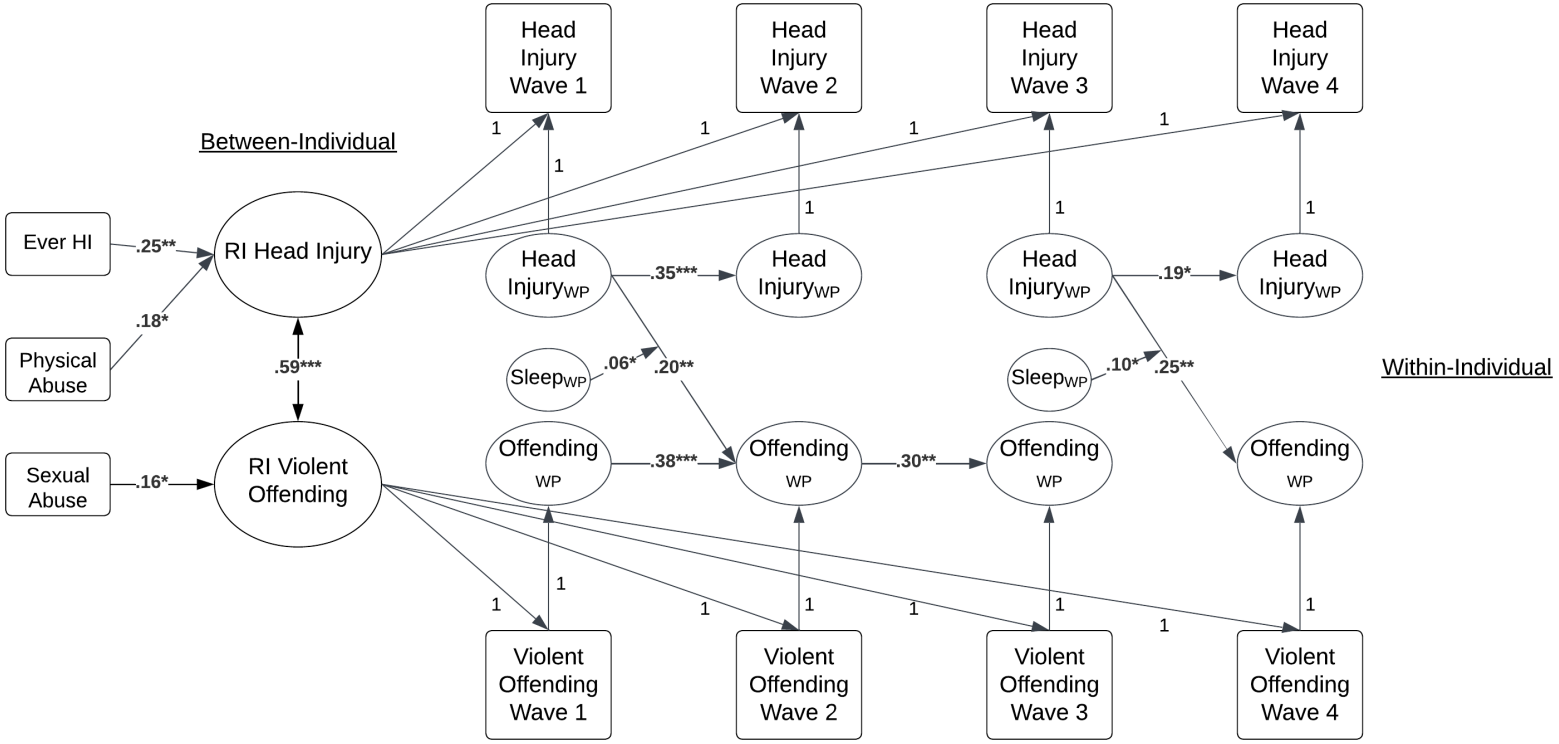
Note: RI-CLPM = random intercept cross-lagged model; CLPM = cross-lagged panel model; CFI = comparative fit index; RMSEA = root mean square error of approximation; SRMR = standardized root mean square residual; SB $\chi 2$ = Satorra-Bentler scaled chi-square difference test.

FIGURE 1 Random intercept cross-lagged model for head injury and offending with sleep disturbance as a moderator



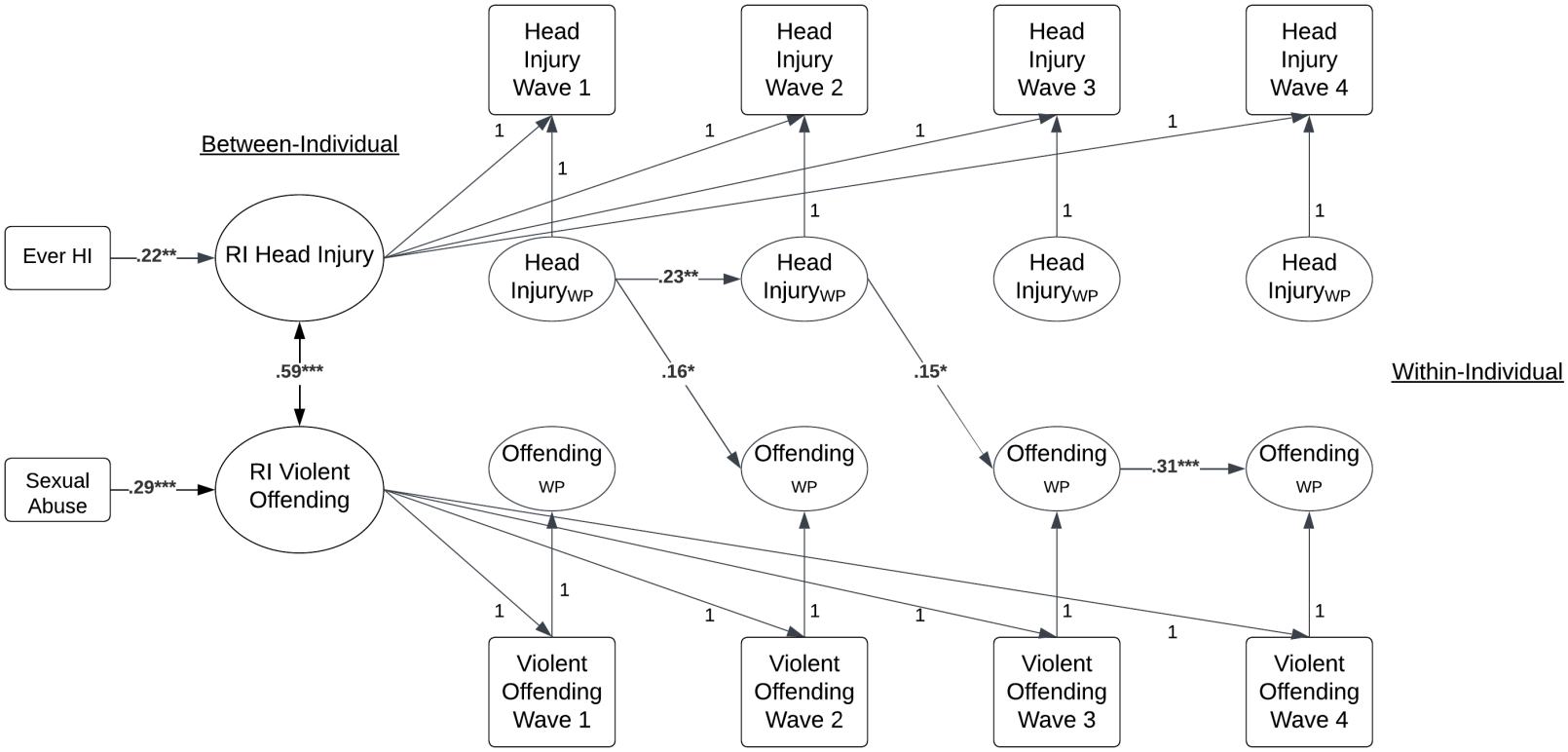
Note: WP = within-individual.

FIGURE 2 Significant parameter estimates of final RI-CLPM for head injury and violent offending for males (n = 872)



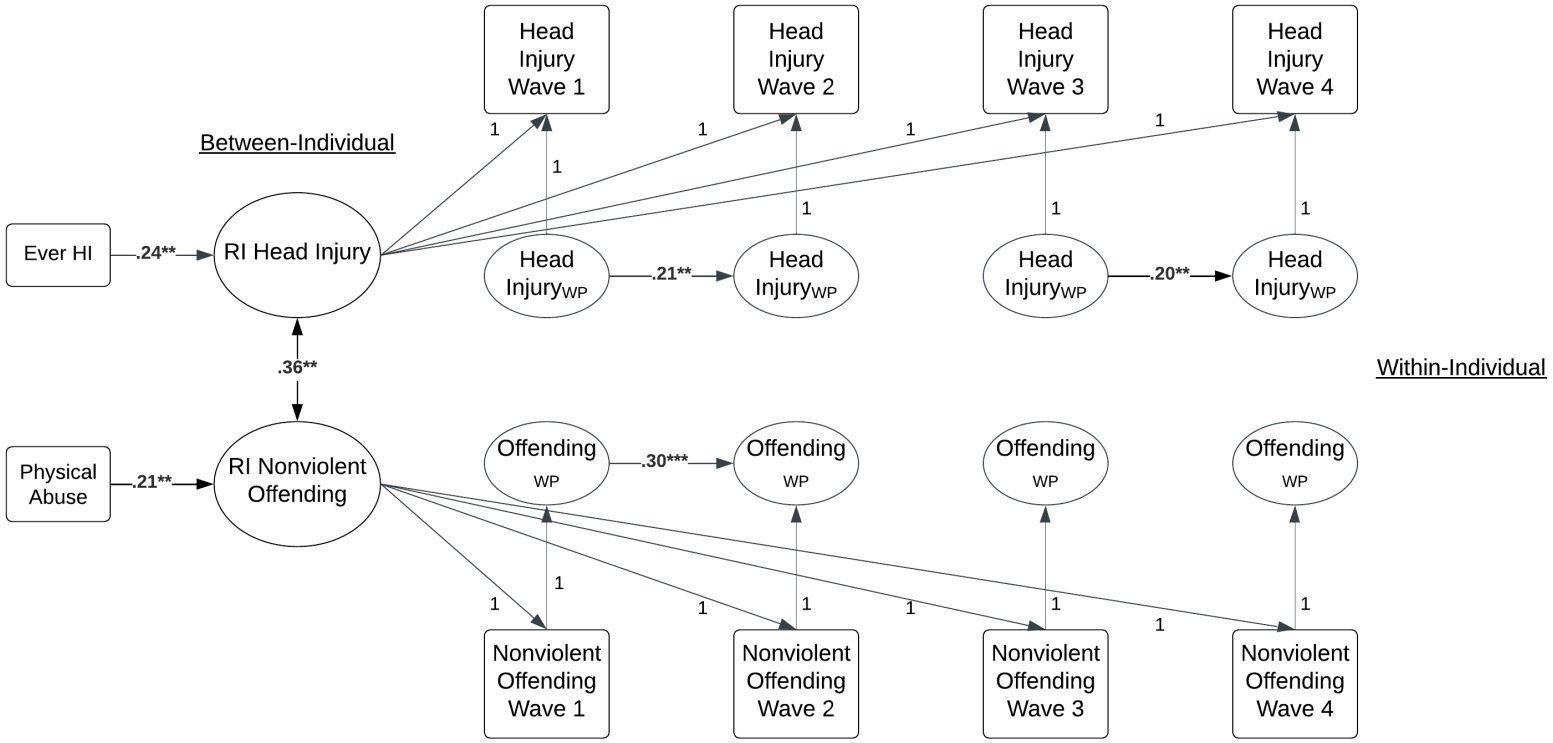
Note: Standardized parameter estimates presented. Non-significant parameters not shown. Model controls for age and race. HI = head injury; RI = random intercept; WP = within-individual. ***$p < .001$; **$p < .01$; *$p < .05$.

FIGURE 3 Significant parameter estimates of final RI-CLPM for head injury and violent offending for females (n = 611)



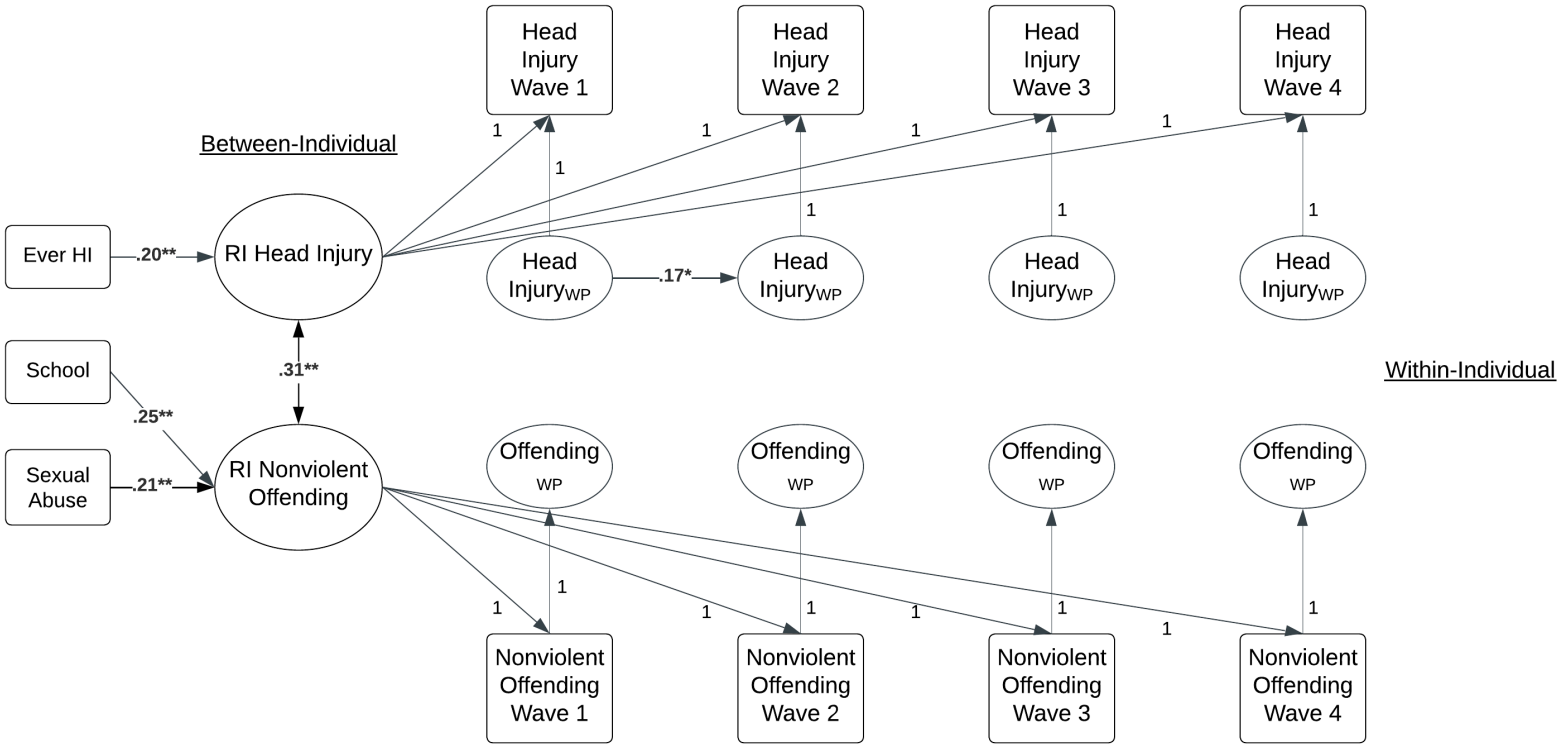
Note: Standardized parameter estimates presented. Non-significant parameters not shown. Model controls for age and race. HI = head injury; RI = random intercept; WP = within-individual. ***$p < .001$; **$p < .01$; *$p < .05$.

FIGURE 4 Significant parameter estimates of final RI-CLPM for head injury and nonviolent offending for males (n = 872)



Note: Standardized parameter estimates presented. Non-significant parameters not shown. Model controls for age and race. HI = head injury; RI = random intercept; WP = within-individual. ***$p < .001$; **$p < .01$.

FIGURE 5 Significant parameter estimates of final RI-CLPM for head injury and nonviolent offending for females (n = 611)



Note: Standardized parameter estimates presented. Non-significant parameters not shown. Model controls for age and race. HI = head injury; RI = random intercept; WP = within-individual. **$p < .01$; *$p < .05$.