Adverse perinatal events and offspring criminal convictions in men and women: A population-based study

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A B S T R A C T

Background: We examined associations of adverse perinatal events with offspring violent and non-violent criminal convictions in men and women.
Methods: All singleton births between 1973 and 1995 ($n = 1,146,570$ men, $n = 1,085,217$ women) were identified through Swedish population-based registers. Information about adverse perinatal events was retrieved from the Medical Birth Register. Outcomes were criminal convictions collected from the National Crime Register. We estimated absolute and relative risks of being convicted of criminal convictions using the Kaplan-Meier method and survival analyses for men and women separately. We also tested for differences in magnitudes of associations for men versus women.
Results: Several adverse perinatal events were associated with an increased risk of violent and non-violent criminal convictions in both men and women. Associations between low birth weight, smallness relative to gestational age and preterm birth with non-violent criminal convictions were statistically significantly higher for men than for women. There was a dose-dependent association between adverse perinatal events with violent and non-violent criminal convictions for both men and women, indicated by the strengthened magnitude of HR estimates with exposure to an increasing number of adverse perinatal events.
Conclusions: Adverse perinatal events are associated with violent and non-violent criminal convictions in men and women, with some differences in risk estimates between sexes. Findings are compatible with theoretical accounts implicating disruption of the neurodevelopment during the perinatal period.

1. Introduction

Adverse perinatal events (i.e., pregnancy and birth related risk factors) are associated with an increased level of mental health and behavioral problems (Bhutta, Cleves, Casey, Cradock, & Anand, 2002; Schlotz & Phillips, 2009). Previous research has shown that adverse perinatal events are linked with an elevated risk for later criminality in the offspring (Liu, Raine, Wuerker, Venables, & Mednick, 2009). Adverse perinatal events arise from a complex combination of physiological and environmental factors (Tibbetts, 2011), which makes events during this time of interest from a biopsychosocial criminological perspective: Deviations from the expected normal course of events during pregnancy and birth are thought of as a prototype of biopsychosocial criminology (Tibbetts, 2011) because in historical and

contemporary writings they have been described as having harmful and long-lasting effects on the fetus (Ferreira, 1965; Liu, 2011). Biopsychosocial criminology also emphasizes the role of the brain in explaining criminality and views the perinatal period as particularly critical, since early insults to the developing brain can alter neuropsychological development, which in turn can result in processing deficits that heighten risk for criminality (Liu & Wuerker, 2005; Moffitt, 1993).

As early as the 1950's, studies have documented a link between adverse events during the perinatal period and later behavior problems in children (Cocchi, Felici, Tonni, & Venanzi, 1984; Pasamanick, Rogers, & Lilienfeld, 1956). Beginning in the 1990's, research was undertaken focusing on the combination of adverse perinatal events and psychosocial adversities for later criminal behavior - so called biosocial interactions (Raine, 2002a). Findings suggested that adverse perinatal

events in combination with maternal rejection (Raine, Brennan, & Mednick, 1994; Raine, Brennan, & Mednick, 1997), a disadvantaged family environment (Piquero & Tibbetts, 1999), poor parenting practices (Hodgins, Kratzer, & McNeil, 2001), or family adversity (Arseneault, Tremblay, Boulerice, & Saucier, 2002) are associated with criminality in affected offspring. Some exceptions should be noted, however: Two studies in particular have failed to support biosocial interactions between adverse perinatal events and sociodemographic factors (Murray et al., 2015; Murray, Irving, Farrington, Colman, & Bloxsom, 2010).

Relatively little is known about the relationship between adverse perinatal events and offspring criminality alone. Using a longitudinal birth cohort from Mauritius, one study found that complications during birth (i.e., prenatal, perinatal, and postnatal complications) increased the risk for externalizing behavior problems at age 11 (Liu et al., 2009). Other studies have reported an increased risk for criminality among children exposed to toxins in utero, with a particular focus on the offspring of mothers who smoke during pregnancy (Brennan, Grekin, & Mednick, 1999; D'Onofrio et al., 2010; Kuja-Halkola, D'Onofrio, Larsson, & Lichtenstein, 2014; Räsänen et al., 1999). Associations have also been reported between fetal growth (birth weight adjusted for gestational age; Pettersson, Larsson, D'Onofrio, Almqvist, & Lichtenstein, 2019), pregnancy interval (time between pregnancies; Class et al., 2018), gestational age (D'Onofrio et al., 2013), and several outcomes, such as criminal convictions. Some exceptions should be noted, however, in terms of studies that have failed to demonstrate associations between birth weight and criminality (Conseur, Rivara, Barnoski, & Emanuel, 1997) and gestational age and criminality (Moster, Lie, & Markestad, 2008; Conseur et al., 1997). Other work has demonstrated an association between small head circumference, a minor physical anomaly (Denno, 1990), in early childhood (age 1 year) and later violent criminal behavior among men (Ikäheimo et al., 2007). Studies prior to this also reported associations for small head circumference with later aggression (Waldrop, Bell, McLaughlin, & Halverson, 1978) and behavior problems (Halverson & Victor, 1976).

While the body of work documenting associations between adverse perinatal events and offspring criminality is growing, few studies have explored the possibility of a dose-dependent relationship wherein greater exposure to adverse perinatal events amplify risk for criminality. Studies considering different types of adverse perinatal events have typically collapsed them together (e.g., Hodgins et al., 2001; Liu et al., 2009). Only one study to date has examined the potential importance of a summative index of adverse perinatal events for later criminality (Murray et al., 2015). This study reported an association between the number of experienced adverse perinatal events and later self-reported violent behavior among both men and women.

Most studies examining adverse perinatal events in relation to criminal behavior have utilized male-only samples, or total population samples with an adjustment for offspring sex. While it is well known that men account for a substantially larger proportion of all crimes than do women (Archer, 2004), no theoretical framework has successfully explained the gender gap in crime fully (e.g., social control; Gottfredson & Hirschi, 1990 and strain; Agnew, 1992; Broidy & Agnew, 1997). As such, research that moves beyond traditional criminological approaches and which can provide insight into potential explanations for this discrepancy is warranted. Biopsychosocial factors in general, but adverse perinatal events in particular, may be helpful for explaining sex differences in crime as the male brain has been theorized to be more susceptible to influences from early risk factors that can affect the normal neurological development (Golding & Fitzgerald, 2019). This could put males at higher risk for developing a variety of disorders (Schore, 2017), and engaging in criminality to a larger extent than women (Raine, 2019). Further, studies have also demonstrated that boys have a higher risk of being born preterm compared to girls (Zeitlin et al., 2002), and it has long been known that boys have a higher incidence of exposure to other pregnancy and birth related complications (Pederson

& Bell, 1970; Williams & Williams, 1985).

Despite the potential for elucidating, at least in part, why males commit more crimes than women, few studies have examined associations between adverse perinatal events and criminality for men and women separately. One study utilizing the Stockholm Birth Cohort (Stenberg & Vågerö, 2006) reported an association between a composite index of adverse perinatal events using the McNeil-Sjöström Scale for Obstetric Complications (McNeil & Sjöström, 1995) and overall offspring criminal convictions for both men and women (Hodgins et al., 2001). When the outcome was limited to violent criminal convictions, the association remained evident for men but not for women, perhaps due to statistical power issues. Another study utilizing data from the 1970 British Cohort Study evaluated maternal smoking during pregnancy, low birth weight, and a combined index of other birth complications (including eclampsia and breech presentation) as predictors of later criminal convictions (Elliott & Shepherd, 2006). Findings suggested that maternal smoking during pregnancy and low birth weight, but no other birth complications, increased the risk for criminal convictions in both men and women (Murray et al., 2010). Maternal smoking during pregnancy, but not preterm birth or intrauterine growth restriction (i.e., small for gestational age), has also been found to be associated with self-reported violent behavior in both men and women (Murray et al., 2015).

In summary, although a relatively large knowledge base exists regarding adverse perinatal events in relation to criminal offending, important gaps in the literature remain to be addressed (Liu, 2011). First, little is known about the role of adverse perinatal events in later criminality for women as compared to men, as no large-scale population-based study has yet examined this. Second, studies using large-scale population-based samples have to date only examined a subset of adverse perinatal events in relation to offspring criminal behavior, leaving several others to be examined (e.g., labor presentation, head circumference). The potential importance of multiple adverse perinatal events affecting later criminal offending in a dose-dependent manner also remains to be addressed through use of a summative index. Third, the bulk of prior studies have tested for associations of adverse perinatal events with later violent criminality; further research is needed that examining associations with violent and non-violent criminal convictions separately. In an effort to address these knowledge gaps, we undertook to separately examine the associations between adverse perinatal events, as a whole and in a summative manner, with offspring criminality in men and women. More specifically, we addressed the following research questions:

I) Which adverse perinatal events are associated with an increased risk of offspring violent and non-violent criminal convictions in men and women?

II) Are associations between adverse perinatal events and offspring violent and non-violent criminal convictions significantly different for men and women?

III) Is there a dose-dependent relationship between the number of adverse perinatal events and offspring violent and non-violent criminal convictions in men and women?

2. Methods

2.1. Data source

We used the unique personal identity numbers assigned to all individuals living in Sweden to link several Swedish population-based registers (Ludvigsson, Otterblad-Olausson, Pettersson, & Ekbom, 2009). Linkage between the registers was based on anonymized personal identity numbers and was approved by the Regional Ethical Review Board in Stockholm (2013/862–31/5). The following registers were used: (1) The Medical Birth Register (MBR), which started in 1973 and contains data on more than 99% of all pregnancies and deliveries in

Sweden, was used to retrieve information about adverse perinatal events. The included variables have previously shown high validity (Källén & Källén, 2003); (2) The Multi-Generation Register (MGR), a record of family genealogies, was used to link children to their biological mother; (3) The Total Population Register (TPR; Ludvigsson et al., 2016), which contains demographic data on all individuals who have a permanent residency in Sweden, was used to obtain information about migration and death where applicable; (4) The National Crime Register (NCR), a cross-jurisdictional record of criminal convictions, was used to retrieve data for all individuals who had been convicted in a Swedish district court at or after age 15, which is the minimum age of criminal responsibility in Sweden; (5) For sensitivity analyses (described below), we used data from the Longitudinal Integration Database for Health Insurance and Labour Market (LISA; Ludvigsson, Svedberg, Olen, Bruze, & Neovius, 2019) to retrieve a proxy measure of socioeconomic status (SES).

2.2. Study population

We identified all singleton births between 1973 and 1995 ($n = 2,343,074$). Children who could not be linked to their biological mother ($n = 13,521$) were excluded. We also excluded those who emigrated ($n = 78,516$) or died ($n = 19,250$) at or before the age of 15 years. The final sample consisted of 2,231,787 individuals: 1,146,570 (51.4%) men and 1,085,217 (48.6%) women.

2.3. Adverse perinatal events

According to the World Health Organization (WHO), the perinatal period starts at 22 completed weeks of gestation until seven days after birth. We divided the adverse perinatal events into infant related and birth/pregnancy related factors. Given earlier diverse findings for associations between adverse perinatal events and offspring criminal offending, we considered adverse perinatal events to be any event during the perinatal period that deviated from the expected normal course of events (i.e., categories not used as reference category).

2.3.1. Infant related factors
Birth weight was coded into four categories; extremely low (≤ 2500 g), low (2501–3500 g), normal (3501–4500 g; reference category), and high (>4500 g). *Size by gestational age* was defined as a birth weight at least two standard deviations (SDs) below or above the mean weight for the given gestational age according to the Swedish fetal growth curve (Marsal et al., 1996), and was coded into small, large, or normal for gestational age. *Head circumference* at birth was divided into small head circumference (≤ 33 cm) and normal head circumference (>33 cm).

2.3.2. Birth/pregnancy related factors
Gestational period was categorized into preterm birth (born before 37 weeks of completed gestation), term birth (born during week 37 to week 41 of completed gestation) and post-term birth (born during or after week 42 of completed gestation). We coded *obstetric delivery* into categories of unassisted vaginal delivery, assisted vaginal delivery (i.e., use of forceps or vacuum), or caesarean section. *Labor presentation* was categorized into normal presentation (i.e., vertex presentation, top of the head first), breech, or other presentation (e.g., transverse lie, oblique).

2.4. Outcome

2.4.1. Criminal behavior
We defined criminal offending as occurrence of a conviction in the NCR, and subdivided occurrences into the first violent criminal convictions and the first non-violent criminal convictions, coded as binary variables. In keeping with previous research, we defined violent criminal convictions as a conviction for homicide, manslaughter, assault,

kidnapping, illegal confinement, unlawful coercion, gross violation of a person's or a woman's integrity, unlawful threats, intimidation, robbery, arson, and threats and violence against an officer (Frisell, Lichtenstein, & Långström, 2011). Non-violent criminal convictions were defined as any criminal conviction that was not a violent criminal conviction, including convictions for sexual crimes (Kuja-Halkola, Pawitan, D'Onofrio, Långström, & Lichtenstein, 2012).

2.5. Statistical analyses

All data management and statistical analyses were performed using SAS software version 9.4 (SAS Institute Inc., Cary, NC) and R 3.6.1 (R Development Core Team, 2020). All analyses were performed for men and women separately. In all our analyses, we followed the participants over time from the day they turned 15 years of age, the minimum age of criminal responsibility in Sweden. Participants were then followed until they were either 1) convicted of a violent or a non-violent crime, 2) emigrated, 3) died, 4) or reached the end of the study period (31 December 2013). Results from analyses of data for the total cohort can be found in Tables S1-S3 of the Supporting Information.

2.5.1. Absolute risks
As a first step, we used the Kaplan-Meier method to estimate the cumulative incidence of being convicted of violent and non-violent crimes among exposed and unexposed men and women respectively, while accounting for censoring (i.e., individuals contributing with unequal lengths of time). Cumulative incidence is an estimate of the probability for an individual to experience the outcome (i.e., violent and non-violent criminal convictions) during a specific period of time. We estimated the cumulative incidence of experiencing the outcome before age 30 (i.e., after 15 years of follow-up).

2.5.2. Comparing men and women
As a next step, we used survival analyses to estimate the relative risk of being convicted of violent and non-violent crimes in adversity-exposed and unexposed men and women separately. Cox proportional hazard regression models were used to estimate hazard ratios (HRs) and 95% confidence intervals (CI). The adverse perinatal events were used as predictor variables, and violent and non-violent criminal convictions were used as outcome variables.

We estimated associations between each individual perinatal factor and the two conviction outcomes among men and women separately, adjusting for birth year to account for potential cohort effects. We further used Wald tests to examine whether the HRs from these models were different for men and women.

2.5.3. Summative index
Lastly, we included all adverse perinatal events in mutually adjusted models to test for independent associations of each perinatal factor with the outcomes. In line with previous research, the categories of adverse perinatal events that were associated with an *increased* risk of the outcomes (i.e., with a HR greater than 1), even after adjusting for the other adverse perinatal events, were compiled into a summative index to examine the risk of experiencing more than one perinatal factor for later criminal convictions in a dose-dependent manner (Brander et al., 2016; Brander et al., 2018). This approach allowed different adverse perinatal events to be included in the summative index for men and women, which was deemed important in view of prior research documenting differences in risk of experiencing adverse perinatal events between men and women (see for example Zeitlin et al., 2002).

2.5.4. Sensitivity analyses
Because much existing work of this kind has focused on adverse perinatal events in combination with psychosocial adversities, we stratified the total sample including both men and women to examine associations between adverse perinatal events and the outcomes based

on levels of SES. SES was defined as the mother's highest educational level achieved before the offspring's 15th birthday. In keeping with previous research, we categorized SES into three educational levels: up to 11 years, (low) 12 to 14 years (medium) and 15 years or more (high; Andersson et al., 2020).

3. Results

3.1. Descriptive statistics

The mean age at first violent and non-violent criminal conviction for men was 20.4 and 19.6 years respectively (SD = 4.6 and 4.4, median (Md) = 19.1 and 18.1, 1st quartile ($q1$) = 16.9 and 16.4, 3rd quartile ($q3$) = 22.4 and 21.4). The mean age at first violent and non-violent criminal conviction for women was 20.2 and 19.2 years respectively (SD = 4.9 and 4.4, Md = 18.5 and 17.7, $q1$ = 16.6 and 16.3, $q3$ = 22.1 and 20.5). Tables 1 and 2 display, for men and women respectively, the cumulative incidence (i.e., estimated probability) of violent and non-violent criminal convictions by exposure to adverse perinatal events during follow-up. The estimated cumulative incidence of being convicted of a violent or a non-violent crime prior to age 30 was, as expected, higher for men than for women. For violent criminal convictions among men, the mean time of follow-up for men was 10.2 years (SD = 5.2), and for non-violent criminal convictions it was 9.0 years (SD = 5.5). For violent criminal convictions among women, the mean time of follow-up for women was 9.6 years (SD = 4.8), and for non-violent criminal convictions it was 9.1 years (SD = 5.0). The Kaplan-Meier survival curves for adverse perinatal events and violent and non-violent criminal convictions are shown in Figs. S1-S4 of the Supporting information.

3.2. Comparing men and women for risk of being convicted of violent and non-violent crime

The HRs for being convicted of violent and non-violent crimes by each adverse perinatal event among men and women are presented in Table 3. In models adjusted for birth year we found the following adverse perinatal events to be associated with an increased risk of being convicted of a violent crime among men and women: extremely low birth weight ($\leq$2500 g; HR = 1.17, 95% CI = 1.13, 1.22 and HR = 1.13, 95% CI: 1.03, 1.25, respectively), low birth weight (2501–3500 g; HR = 1.16, 95% CI: 1.15, 1.18 and HR = 1.12, 95% CI: 1.09, 1.17, respectively), small for gestational age (HR = 1.20, 95% CI: 1.15, 1.25 and HR = 1.21, 95% CI: 1.10, 1.32, respectively), small head circumference ($\leq$33 cm; HR = 1.16, 95% CI: 1.14, 1.18 and HR = 1.16, 95% CI: 1.12, 1.21, respectively), and post-term birth ($\geq$42 weeks; HR = 1.03, 95% CI: 1.01, 1.06 and HR = 1.10, 95% CI: 1.03, 1.17, respectively). Preterm birth ($<$37 weeks) was associated with an increased risk of violent criminal convictions for men (HR = 1.09, 95% CI: 1.06, 1.13) but not women (HR = 1.00, 95% CI: 0.92, 1.09). High birth weight ($>$4500 g) and being born with caesarean section was associated with a decreased risk for violent criminal convictions among men (HR = 0.94, 95% CI: 0.90, 0.98 and HR = 0.97, 95% CI: 0.94, 0.99, respectively), but not women (HR = 0.87, 95% CI: 0.75, 1.00 and HR = 0.96, 95% CI: 0.91, 1.02, respectively). Being born in breech was associated with a decreased risk for violent criminal convictions among women (HR = 0.85, 95% CI: 0.75, 0.97), but not men (HR = 0.97, 95% CI: 0.92, 1.03). Lastly, assisted vaginal delivery was associated with a decreased risk of violent criminal convictions among both men and women (HR = 0.89, 95% CI: 0.87, 0.92 and HR = 0.80, 95% CI: 0.74, 0.88).

For non-violent criminal convictions we found similar but generally somewhat weaker associations for both men and women. The following variables were associated with an increased risk of conviction for a non-

Table 1
Rates of violent and nonviolent criminal convictions by adverse perinatal events among men.

Adverse perinatal events	Population in each group, N	Number of outcomes		Follow-up time in person-years		Cumulative incidence of first criminal conviction in % at age 30	
		Violent	Non-violent	Violent	Non-violent	Violent	Non-violent
Total	1,146,570	68,896	255,348	15,189,657	13,037,401		
Infant related							
Birth weight							
Extremely low	35,202 (3.1)	2324	8120	462,370	395,565	7.2	24.9
Low	455,131 (39.7)	29,978	106,888	6,119,283	5,212,744	7.1	25.2
Normal	607,735 (53.0)	34,085	130,552	7,993,319	6,893,559	6.2	23.3
High	45,863 (4.0)	2368	9273	581,719	506,073	5.8	22.4
Missing	2639 (0.2)	141	515	32,975	29,457		
Gestational age							
Normal	1,069,312 (93.3)	63,876	237,305	14,133,814	12,139,970	6.6	24.0
Small	35,344 (3.1)	2617	9073	510,518	426,375	7.7	26.6
Large	35,995 (3.1)	1965	7427	460,180	399,527	6.1	22.7
Missing	5919 (0.5)	438	1543	85,146	71,527		
Head circumference							
Small	184,485 (16.1)	12,731	44,817	2,531,128	2,147,107	6.4	25.7
Normal	936,735 (81.7)	54,822	205,864	12,403,554	10,665,802	7.4	23.8
Missing	25,350 (2.2)	1343	4667	254,975	224,491		
Birth/pregnancy related							
Gestational period							
Preterm birth	58,049 (5.1)	3748	13,074	748,748	643,640	7.1	24.6
Term birth	978,257 (85.3)	58,057	215,166	12,832,924	11,043,882	6.5	23.9
Post-term birth	106,871 (9.3)	6789	26,047	1,554,350	1,306,587	6.7	25.4
Missing	3393 (0.3)	302	1061	53,636	43,290		
Labor presentation							
Normal	797,190 (69.5)	47,831	181,608	11,033,826	9,368,341	6.5	24.5
Breech	21,472 (1.9)	1243	4602	292,705	251,035	6.4	23.2
Other	35,113 (3.1)	2131	7850	472,155	403,389	6.7	24.1
Missing	292,795 (25.5)	17,691	61,288	3,390,972	3,014,634		
Obstetric delivery							
Unassisted vaginal birth	950,371 (82.9)	57,808	214,177	12,668,400	10,845,568	6.6	24.3
Caesarean section	118,729 (10.4)	6888	24,919	1,506,986	1,312,985	6.5	23.1
Assisted vaginal delivery	77,470 (6.8)	4200	16,252	1,014,271	878,847	6.1	22.9

Table 2
Rates of violent and nonviolent criminal convictions by adverse perinatal events among women.

Adverse perinatal events	Population in each group, *N* (%)	Number of outcomes		Follow-up time in person-years		Cumulative incidence of first criminal conviction in % at age 30	
		Violent	Non-violent	Violent	Non-violent	Violent	Non-violent
Total	1,085,217	12,531	90,007	14,776,450	13,949,008		
Infant related							
Birth weight							
Extremely low	38,707 (3.6)	477	3277	531,2120	501,220	1.3	8.9
Low	542,261 (50.0)	6621	46,431	7,499,525	7,068,286	1.3	8.9
Normal	480,034 (44.2)	5204	38,358	6,434,594	6,085,724	1.2	8.4
High	21,756 (2.0)	204	1730	279,930	264,432	1.1	8.6
Missing	2459 (0.2)	25	211	31,182	29,344		
Gestational age							
Normal	1,012,549 (93.3)	11,623	83,758	13,753,706	12,985,866	1.2	8.7
Small	36,866 (3.4)	494	3215	541,640	509,321	1.4	9.1
Large	31,287 (2.9)	332	2464	399,767	378,155	1.2	8.6
Missing	5515 (0.5)	82	570	81,338	75,664		
Head circumference							
Small	278,264 (25.6)	3593	24,593	3,893,136	3,664,755	1.4	9.2
Normal	784,662 (72.3)	8654	63,770	10,655,372	10,067,620	1.2	8.5
Missing	22,291 (2.1)	284	1644	227,942	216,632		
Birth/pregnancy related							
Gestational period							
Preterm birth	47,557 (4.4)	548	3798	626,820	592,890	1.2	8.5
Term birth	936,726 (86.3)	10,716	77,177	12,571,196	11,873,060	1.2	8.7
Post-term birth	97,783 (9.0)	1210	8663	1,527,115	1,435,706	1.2	8.5
Missing	3151 (0.3)	57	369	51,319	47,350		
Labor presentation							
Normal	752,081 (69.3)	8426	61,978	10,707,473	10,097,839	1.2	8.6
Breech	24,947 (2.3)	240	1984	350,255	330,606	1.0	8.4
Other	34,871 (3.2)	375	2865	486,475	458,579	1.1	8.6
Missing	273,318 (25.2)	3490	23,180	3,232,247	3,061,982		
Obstetric delivery							
Unassisted vaginal birth	923,559 (85.1)	10,808	77,069	12,650,518	11,939,288	1.2	8.8
Caesarean section	106,143 (9.8)	1198	8672	1,386,652	1,310,331	1.2	8.7
Assisted vaginal delivery	55,515 (5.1)	525	4266	739,281	699,388	1.0	8.2

Table 3
Associations between adverse perinatal events and violent and nonviolent criminal convictions among men and women.

	Violent			Non-violent		
	Model adjusted for birth year			Model adjusted for birth year		
Adverse perinatal events	Men	Women		Men	Women	
Infant related	HR (95% CI)	HR (95% CI)	p-value[a]	HR (95% CI)	HR (95% CI)	p-value[a]
Birth weight						
Extremely low	1.17 (1.13,1.22)	1.13 (1.03,1.25)	0.43	1.08 (1.06,1.10)	1.05 (1.02,1.09)	0.18
Low	1.16 (1.15,1.18)	1.12 (1.09,1.17)	0.07	1.09 (1.09,1.10)	1.06 (1.05,1.08)	0.01
Normal	1	1		1	1	
High	0.94 (0.90,0.98)	0.87 (0.75,1.00)	0.31	0.96 (0.94,0.98)	1.01 (0.97,1.06)	0.05
Gestational age						
Normal	1	1		1	1	
Small for gestational age	1.20 (1.15,1.25)	1.21 (1.10,1.32)	0.97	1.14 (1.11,1.16)	1.06 (1.02,1.10)	0.02
Large for gestational age	0.93 (0.89,0.97)	0.93 (0.83,1.03)	0.99	0.94 (0.91,0.96)	0.97 (0.93,1.01)	0.28
Head circumference						
Small	1.16 (1.14,1.18)	1.16 (1.12,1.21)	0.87	1.10 (1.09,1.11)	1.08 (1.06,1.10)	0.22
Normal	1	1		1	1	
Birth/pregnancy related						
Gestational period						
Preterm birth	1.09 (1.06,1.13)	1.00 (0.92,1.09)	0.06	1.03 (1.01,1.05)	0.97 (0.94,1.00)	<0.001
Term birth	1	1		1	1	
Post-term birth	1.03 (1.01,1.06)	1.10 (1.03,1.17)	0.06	1.08 (1.07,1.09)	1.04 (1.02,1.06)	0.40
Labor presentation						
Normal	1	1		1	1	
Breech	0.97 (0.92,1.03)	0.85 (0.75,0.97)	0.08	0.94 (0.91,0.97)	0.97 (0.93,1.01)	0.32
Other	1.02 (0.98,1.06)	0.95 (0.86,1.06)	0.23	0.99 (0.96,1.01)	1.00 (0.96,1.04)	0.82
Obstetric delivery						
Unassisted vaginal birth	1	1		1	1	
Caesarean section	0.97 (0.94,0.99)	0.96 (0.91,1.02)	0.84	0.94 (0.93,0.95)	0.99 (0.96,1.01)	0.01
Assisted vaginal delivery	0.89 (0.87,0.92)	0.80 (0.74,0.88)	0.04	0.93 (0.91,0.94)	0.92 (0.90,0.95)	0.61

[a] p-values to examine whether the HRs were statistically significantly different between men and women.

violent crime for men and women: extremely low birth weight (≤2500 g; HR = 1.08, 95% CI: 1.06, 1.10 and HR = 1.05, 95% CI: 1.02, 1.09, respectively), low birth weight (2501–3500 g; HR = 1.09, 95% CI: 1.09, 1.10 and HR = 1.06, 95% CI: 1.05, 1.08; respectively), small for gestational age (HR = 1.14, 95% CI: 1.11, 1.16 and HR = 1.06, 95% CI: 1.02, 1.10, respectively), small head circumference (≤33 cm; HR = 1.10, 95% CI: 1.09, 1.11 and HR = 1.08, 95% CI: 1.06, 1.10, respectively) and post-term birth (≥42 weeks; HR = 1.08, 95% CI: 1.07, 1.09 and HR = 1.04, 95% CI: 1.02, 1.06, respectively). Preterm birth (<37 weeks) was associated with non-violent criminal convictions for men (HR = 1.03, 95% CI: 1.01, 1.05) but not women (HR = 0.97, 95% CI: 0.94, 1.00).

None of the adverse perinatal events that increased the risk for violent criminal convictions differed statistically significant between men and women. Assisted vaginal delivery decreased the risk for violent criminal convictions for both men and women, and the estimate was statistically significantly lower for women than men ($p = 0.04$). Regarding non-violent criminal convictions, three adverse perinatal events increased risk to a significantly greater extent for men than for women: low birth weight (2501–3500 g; $p = 0.01$), small for gestational age ($p = 0.02$) and preterm birth (<37 weeks; $p < 0.001$). Among the adverse perinatal events that decreased the risk for non-violent criminal convictions, the estimates for high birth weight and caesarean section were statistically significantly lower for men than for women (ps = 0.05 and 0.01).

3.3. Hazard ratios for violent and non-violent criminal convictions in mutually adjusted models

Fig. 1 shows the HRs for violent and non-violent criminal convictions for each of the adverse perinatal events from mutually adjusted models that included all adverse perinatal events as predictors. The following variables increased the risk for violent criminal convictions among men: extremely low and low birth weight (≤2500 g, 2501–3500 g; HR = 1.09,

95% CI: 1.02, 1.17 and HR = 1.15, 95% CI: 1.13, 1.17, respectively), small for gestational age (HR = 1.10, 95% CI: 1.05, 1.16), small head circumference (≤33 cm; HR = 1.07, 95% CI: 1.04, 1.09), preterm birth (<37 weeks; HR = 1.06, 95% CI: 1.01, 1.12) and post-term birth (≥42 weeks; HR = 1.08, 95% CI: 1.05, 1.12). Variables that increased the risk for non-violent criminal convictions among men were: extremely low and low birth weight (≤2500 g, 2501–3500 g and HR = 1.04, 95% CI: 1.01, 1.08; HR = 1.09, 95% CI: 1.07, 1.10, respectively), small for gestational age (HR = 1.09, 95% CI: 1.06, 1.13), small head circumference (≤33 cm; HR = 1.06, 95% CI: 1.05, 1.07), and post-term birth (≥42 weeks; HR = 1.11, 95% CI: 1.10, 1.13). Variables that increased the risk for violent and non-violent criminal convictions among women were: low birth weight (HR = 1.08, 95% CI: 1.03, 1.13 and HR = 1.05, 95% CI: 1.04, 1.07, respectively), small head circumference (≤33 cm; HR = 1.13, 95% CI: 1.07, 1.19 and HR = 1.06, 95% CI: 1.04, 1.08, respectively), and post-term birth (≥42 weeks; HR = 1.09, 95% CI: 1.02, 1.17 and HR = 1.04, 95% CI: 1.01, 1.06, respectively). The HR estimates are presented in Tables S4-S5 of the Supporting Information.

3.4. Hazard ratios for violent and non-violent criminal convictions predicted from the summative index

HRs for being convicted of violent and non-violent crimes as predicted from the summative index among men and women are presented in Table 4. We found that being exposed to an increasing number of adverse perinatal events elevated the risk for violent and non-violent convictions for both men and women in a dose-dependent manner. In models adjusted for birth year we found that being exposed to one perinatal factor increased the risk of being convicted for a violent crime by 11% (HR = 1.11, 95% CI: 1.09, 1.13) and by 7% for a non-violent crime (HR = 1.07, 95% CI: 1.06, 1.08) for men, and by 9% (HR = 1.09, 95% CI: 1.04, 1.13) and by 5% (HR = 1.05, 95% CI: 1.04, 0.07) for women. In contrast, being exposed to four adverse perinatal events
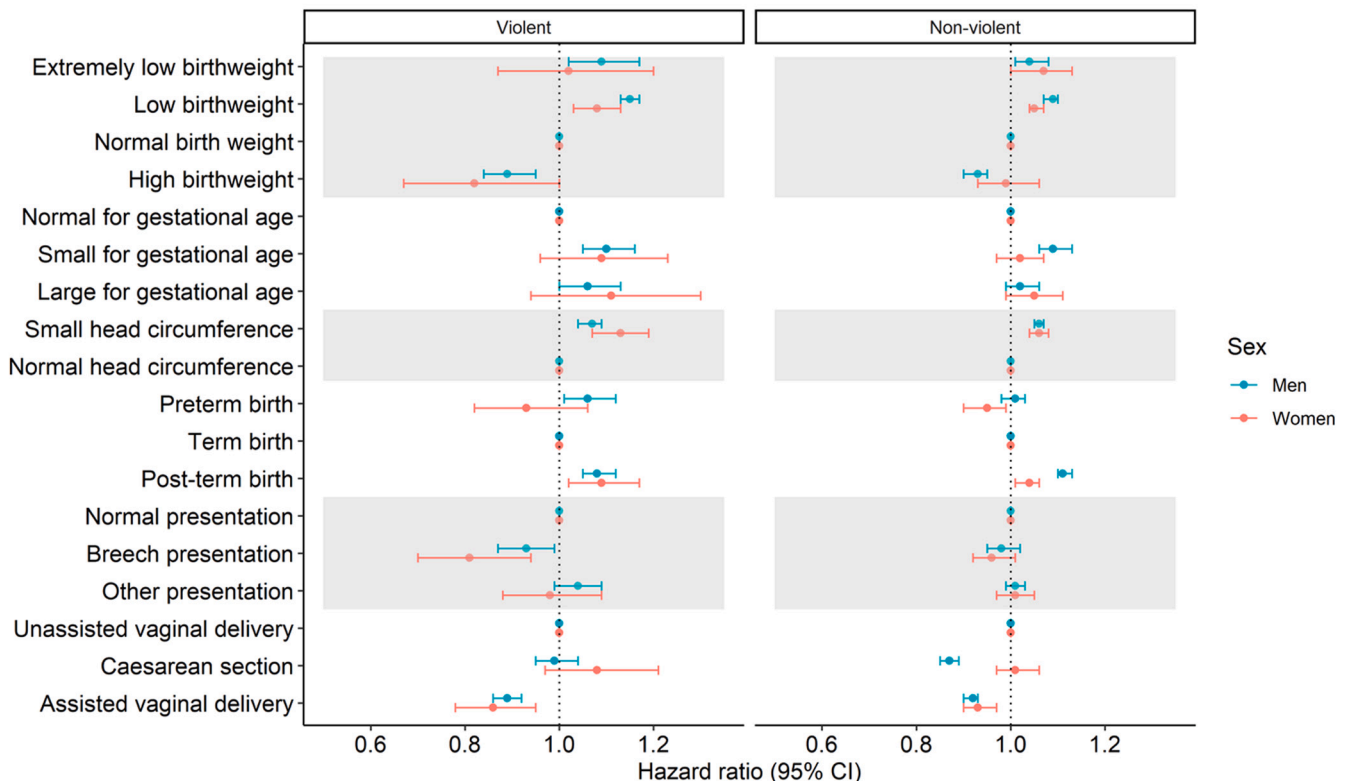
Perinatal factors

Fig. 1. Associations from Mutually Adjusted Models for Violent and Non-Violent Criminal Convictions by Adverse perinatal events in Men and Women.

Table 4

Associations for the summative index of adverse perinatal events with violent and non-violent criminal convictions among men and women.

	Violent				Non-violent			
	Model adjusted for birth year				Model adjusted for birth year			
No of perinatal events	Men[a]		Women[b]		Men[c]		Women[b]	
	N (%)	HR (95% CI)	N (%)	HR (95% CI)	N (%)	HR (95% CI)	N (%)	HR (95% CI)
0	555,750 (48.5)	1	419,197 (38.6)	1	558,378 (48.7)	1	419,197 (38.6)	1
1	393,172 (34.3)	1.11 (1.09,1.13)	436,006 (40.2)	1.09 (1.04,1.13)	407,319 (35.5)	1.07 (1.06,1.08)	436,006 (40.2)	1.05 (1.04,1.07)
2	141,749 (12.4)	1.23 (1.20,1.26)	221,276 (20.4)	1.22 (1.17,1.28)	154,097 (13.4)	1.13 (1.12,1.15)	221,276 (20.4)	1.11 (1.09,1.13)
3	50,172 (4.4)	1.25 (1.21,1.30)	8738 (0.8)	1.43 (1.20,1.70)	24,854 (2.2)	1.17 (1.14,1.20)	8738 (0.8)	1.19 (1.11,1.28)
4	5727 (0.5)	1.31 (1.19,1.44)	–	–	1922 (0.2)	1.41 (1.30,1.52)	–	–

[a] Extremely low and low birth weight ($\leq$2500 g, 2501–3500 g), small for gestational age, small head circumference ($\leq$33 cm), preterm birth ($<$37 weeks), post-term birth ($\geq$42 weeks).

[b] Low birth weight (2501–3500 g), small head circumference ($\leq$33 cm), post-term birth ($\geq$42 weeks).

[c] Extremely low and low birth weight ($\leq$2500 g, 2501–3500 g), small for gestational age, small head circumference ($\leq$33 cm), post-term birth ($\geq$42 weeks).

elevated the risk of being convicted for a violent crime by 31% (HR = 1.31, 95% CI: 1.19, 1.44) and by 41% for a non-violent crime (HR = 1.41, 95% CI: 1.30, 1.52) among men. For women, being exposed to three adverse perinatal events increased the risk for violent and non-violent criminal convictions with 43% (HR = 1.43, 95% CI: 1.20, 1.70) and 19% (HR = 1.19, 95% CI: 1.11, 1.28), respectively. Unadjusted estimates can be found in the Supporting Information (Table S6-S7).

3.5. Sensitivity analysis

HR estimates were largely unaffected by stratifying the total sample, including men and women, based on levels of SES. If anything, HRs were somewhat attenuated across all three levels of SES (low, medium, and high; see Table S8 in Supporting Information).

4. Discussion

In this large-scale population-based study, we found that several adverse perinatal events were associated with an increased risk of violent and non-violent criminal convictions. These results are not only in line with findings from previous research (Liu et al., 2009), but also extend these. Specifically, we add to the existing literature by showing that the exposure to adverse perinatal events increases the risk of violent *and* non-violent criminal convictions, in both men *and* women. Further, we found evidence for a dose-dependent relationship between adverse perinatal events and criminal behavior, whereby the exposure to an increasing number of adverse perinatal events elevated the risk for violent and non-violent convictions in both men and women. Additionally, our findings suggest that there may be different adverse perinatal events that heightened the risk of violent and non-violent criminal convictions for men compared to women, even though they are few. For example, observed associations for low birth weight and preterm birth with non-violent criminal convictions were significantly higher for men than for women. These findings build on the existing knowledge regarding the potential importance of early risk factors for criminal offending and point to a dose-dependent relationship.

We also found that small head circumference at birth was associated not only with violent criminal convictions as reported in earlier studies (Ikäheimo et al., 2007) but also with non-violent criminal convictions. These findings were evident for both men and women. Small head circumference has in the previous literature been referred to as a minor physical anomaly (Denno, 1990). From a biopsychosocial criminological perspective, minor physical anomalies have been viewed as reflecting physical and neural maldevelopment of the fetus during pregnancy,

potentially due to both genetic and environmental influences (Raine, 2002b; Raine, 2019). Minor physical anomalies have long been a known correlate of male aggression (Waldrop et al., 1978) and criminality (Raine, 2013), but the current results indicate that this association extends to criminal offending among women.

One previous study using a sample that overlapped partly with the present study's, reported a reduced risk of any criminal conviction among offspring who were born preterm (D'Onofrio et al., 2013). This association remained even among discordant siblings, pointing to an independent association between being born preterm and later criminal offending. Being born preterm would thus serve as a protective factor for later criminality. We found that in models adjusted for birth year, preterm birth increased the risk for violent and non-violent criminal convictions among men, but not women. However, in mutually adjusted models, preterm birth was associated with violent criminal convictions but not non-violent convictions, among men, but not women. The discrepancy in findings may be due to the fact that the present study examined men and women separately, whereas the previous study (D'Onofrio et al., 2013) used a total population sample with an adjustment for offspring sex. Another explanation may relate to the different outcomes studied: whereas the present study utilized violent and non-violent criminal convictions as separate outcomes and D'Onofrio et al. (2013) employed any criminal conviction as the outcome.

Taken together, these findings highlight the importance of examining men and women separately when studying associations between adverse perinatal events and criminal convictions, as well as studying violent and non-violent criminal convictions as separate outcomes. The male brain has been suggested to be more susceptible to influences early in life that can disrupt normative neurological development (Golding & Fitzgerald, 2019), and it is well-known that preterm birth is associated with behavioral and psychological problems in later life (Bhutta et al., 2002). Our findings suggest that the association between preterm birth and criminal offending should be further investigated to better understand whether this is a factor contributing to the higher overall rate of criminal convictions for men as compared to women.

One previous study has demonstrated associations between adverse perinatal events and later self-reported violent behavior in a dose-dependent manner, among both men and women (Murray et al., 2015). Our results are in line with these findings and suggest that when adverse perinatal events accumulate in the same individual (up to four for men and up to three for women in the present study), the risk for criminal convictions in the offspring increases for both men and women. The dose-dependent association between adverse perinatal events and offspring criminality is in line with biopsychosocial criminological theory, which suggest that adverse perinatal events contribute to a

disruption of neuropsychological development, which in turn can heighten the risk for criminal behavior (Raine, 2002c). It is possible that the accumulation of adverse perinatal events in the same individual index disruption of fetal development during pregnancy more effectively than exposure to a single event. This may further be why we see relatively weak associations between individual adverse perinatal events with offspring criminal convictions, as well as low cumulative incidences, even though there are some indications that certain adverse perinatal events are more important than others (e.g., smallness for gestational age). Further research is needed to clarify the nature and etiological basis of the dose-dependent association between perinatal events and later criminal behavior in offspring, which in turn can inform clinical practice and possibly prevention efforts.

Interestingly, the adverse perinatal events that evidenced an association with criminal offending in the mutually adjusted models differed for men and women. For men, the summative index encompassed extremely low and low birthweight, small for gestational age, small head circumference, and post-term birth for non-violent criminal convictions, with the addition of preterm birth for violent criminal convictions. For women, the summative index encompassed of low birth weight, small head circumference, and post-term birth. The implication is that certain adverse perinatal events, when accounting for all others, are more important for men than for women and vice versa. We opted for an empirically driven approach that allowed for different adverse perinatal events to be included in the summative indices for men and women respectively. Our results highlight the need to differentiate between men and women in the study of adverse perinatal events in relation to criminal convictions, since men and women likely are at different risk of experiencing adverse perinatal events (Zeitlin et al., 2002), as well as engage in criminality. This approach was further supported by the HR estimates for the summative index in the total population (Table S3 in Supporting Information), which in general were not significant or in most cases exhibited overlapping CIs. The dose-dependent relationship between adverse perinatal events and offspring criminal behavior should be explored more extensively in future research to better understand the differences between men and women.

Some unexpected findings in our study should also be noted. Certain adverse perinatal events were associated with a decreased risk of violent and non-violent criminal convictions (e.g., breech presentation, assisted vaginal delivery). Breech presentation, as well as other adverse perinatal events, have previously been related to a lack of oxygen to the fetus (i.e., anoxia), which in turn has been described as a risk factor for criminal offending (Tibbetts, 2011). No study thus far has specifically examined breech presentation in relation to criminal offending, let alone different types of breech positions (e.g., frank breech, complete breech). Further research using other samples is needed to explicate the role of different breech presentations and other aspects of delivery on risk for later criminality.

In our sensitivity analyses, we stratified the full sample including men and women based on levels of SES. Previous work has reported associations between exposure to adverse perinatal events in combination with psychosocial adversities, such as maternal rejection (Raine et al., 1994; Raine et al., 1997) and a disadvantaged family environment (Piquero & Tibbetts, 1999) and later criminal behavior in the offspring. However, a few exceptions should be noted though (Murray et al., 2010; Murray et al., 2015). In the current study, HR estimates were largely unaffected by stratifying the sample into levels of SES, if anything they were somewhat attenuated for all groups.

Findings from the present study should be considered in the light of certain limitations. Some of our reported associations, particularly those for the female portion of the sample, need to be interpreted with caution because of the small number of individuals being exposed to particular adverse perinatal events, as well as the small portion of criminal offenders among females. Owing to these factors, HR estimates for females were less precise than those for males, with wider confidence intervals.

Another limitation is that, although the great majority of births in

Sweden are recorded in the MBR, there are still 1–3% of all births during each of the past 20 years that are missing from the register (the National Board of Health and Welfare, 2021). While the MBR contains information of varying quality, the adverse perinatal events included in the present study have previously shown high validity (Källén & Källén, 2003). It is also important to acknowledge that our criminal convictions data relied on official records, which may not be representative of all men and women who have engaged in criminal activity. While registry data reduces the risk of misclassification in one way by limiting recall bias that is often associated with interview data, the results in the present study assume the same level of misclassification of criminal convictions for men and women. While more research is needed on this specific topic, especially in relation to registry data, there is some evidence for a more lenient treatment of female offenders as compared to male offenders (Doerner & Demuth, 2014). Lastly, we performed sensitivity analyses in the total sample of men and women, stratified on levels of SES. Ideally, this would have been done in men and women separately but was not possible due to statistical power restrictions.

5. Conclusions

The present study demonstrates that adverse perinatal events increase the risk not only for violent but also for non-violent criminal convictions. These associations were found for both men and women. In addition, we found evidence of a dose-dependent relationship between adverse perinatal events and violent and non-violent criminal convictions, meaning that an increasing number of adverse perinatal events enhanced the risk of violent and non-violent criminal convictions in both men and women. This finding is in line with biopsychosocial criminology theory which suggest that adverse perinatal events have a detrimental impact on the neuropsychological development during the perinatal period, which operates to increase the risk for future criminal behavior.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jcrimjus.2021.101879.

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