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Michelle O'Sullivan, Emily Glorney, Annette Sterr, Michael Oddy, Sara da Silva Ramos

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Title: Traumatic brain injury and violent behavior in females: A systematic review

Michelle O' Sullivan[a] (corresponding author)

School of Psychology, University of Surrey

Emily Glorney[b]

School of Law, Royal Holloway, University of London

Annette Sterr[a]

School of Psychology, University of Surrey

Michael Oddy[c]

The Disabilities Trust Foundation, UK

Sara da Silva Ramos[c]

The Disabilities Trust Foundation, UK

[a]*School of Psychology, University of Surrey, Guildford, Surrey, UK, GU2 7XH*

Tel: +44 (0) 1483 683551

E-mail: m.o'sullivan@surrey.ac.uk

[b]*School of Law, Royal Holloway, University of London, Egham, Surrey, UK, TW20 0EX*

[c]*The Disabilities Trust Foundation, 32 Market Place, Burgess Hill, West Sussex, UK, RH15 9NP*

Abstract

Background: Research on causes and consequences of neurodisability has established a positive link between traumatic brain injury (TBI) and risk of violence among males. The nature and contribution of TBI to violence risk in females is equivocal and research with females is under-represented in the domain. The primary objective of this paper was to systematically review the strength of results of empirical research into the relationship between TBI and violence in females. *Methods:* Three databases were searched (PsychINFO, Scopus, and PubMed) and supplemented with citation searches (until February, 2013). Methodological rigor was appraised using the Cochrane Handbook's general guidance on non-experimental studies. *Results:* Only six of 153 identified papers met inclusion criteria. Three studies provided evidence of a positive relationship between violence and TBI in females specifically. The remaining found no significant gender differences between levels of post-TBI violence, suggesting females exhibit similar levels of violence to males. The studies contribute knowledge of other factors that may influence post-TBI violence in females, including psychiatric comorbidities and childhood abuse. It was concluded that the strength of evidence suggesting a relationship between TBI and violence in females is poor considering methodological limitations and scarcity of research. However, key findings herein indicate utility of further research to inform intervention and management.

Key Words: brain injury; female offenders; violence; systematic review; forensic; neurodisability

1. Introduction

1.1. Traumatic brain injury

Traumatic brain injury (TBI) is defined as 'an alteration in brain function, or other evidence of brain pathology, caused by an external force' (p. 1638; Menon, Schwab, Wright, & Maas, 2010), capturing the range of presentations that fit under the TBI diagnostic umbrella including loss of or decreased consciousness, any loss of memory, neurological deficits, and any alteration in mental state (e.g., confusion)(Menon et al., 2010). TBI is the most common form of acquired brain injury (ABI; Fleminger & Ponsford, 2005), with an estimated prevalence of 8.5% (Silver, Kramer, Greenwald, & Weissman, 2001) across all levels of severity. Annual incidence of TBI ranges from 180-250 per 100,000 in the US (Bruns & Hauser, 2003), and 91-419 per 100,000 in England (Tennant, 2005); however, rates may overlook milder TBI due to reliance on medical records (Tennant, 2005) and associated diagnostic and selection biases (Dean, O'Neill, & Sterr, 2012; Feigin et al., 2013). TBI severity traditionally has been classified by scores on the Glasgow Coma Scale (GCS; World Health Organization, 2006). Other commonly used measures include post-traumatic amnesia (PTA) and length of loss of consciousness (LOC; Sherer, Struchen, Yablon, Wang, & Nick, 2008). Researchers have not reached a consensus regarding the definition and classification systems for TBI, making comparison across studies difficult (Corrigan, Selassie, & Orman, 2010) and so highlighting the need for systematic reviews to lend coherence to the literature.

Up to twice the rate of TBI has been found in males than females in the general population (Hillbom & Holm, 1986; Hirtz et al., 2007). However, the prevalence of TBI across males and females may be an artifact of the research process (e.g., studies adopting a threshold of LOC for study inclusion might exclude groups with mild TBI without LOC). Research indicates that women typically have a high prevalence of mild TBI, whereas, conversely, men

with TBI are typically more in the moderate to severe range (Diamond, Harzke, Magaletta, Cummins, & Frankowski, 2007). Reported gender differences in prevalence of TBI across severities may be attributable to gender-related behavioral patterns and factors(e.g., intimate partner violence (Valera & Berenbaum, 2003) and decreased likelihood of reporting mild TBIs.

1.2. TBI and violence

For the purpose of this review, the definition of violence suggested by Monahan et al. (2001) is adopted. Violence is confined to physical acts that could cause harm to others, indicating the serious nature of violent behavior. Violence 'includes acts of battery that result in physical injury; sexual assaults; assaultive acts that involve the use of a weapon; or threats made with a weapon' (p.17), consistent with forensic mental health literature.

TBI can result in an array of cognitive, emotional, physical, and behavioral sequelae. Some research suggests violence and impulsive behaviors are both antecedents and consequences of TBI (Anderson, Bechara, Damasio, Tranel, & Damasio, 1999). TBI has been associated with increased risk of developing aggression (Alderman, 2007; Cole et al., 2008; Rao et al., 2009; Visscher, van Meijel, Stolker, Wiersma, & Nijman, 2011). Aggression and violence following TBI has been characterized as unpredictable and ill-directed, which can occur in the absence of clear triggers or provocation (Eslinger, Grattan, & Geder, 1995; Wood & Liossi, 2006). Research from the Swedish population register found that individuals with TBI have a significantly increased risk of committing a violent crime (Fazel, Lichtenstein, Grann, & Långström, 2011). Prisoners with TBI also have higher reported rates of reoffending (Williams et al., 2010). Although TBI cannot be assumed to be the sole cause of violence, it appears that the cognitive and behavioral sequelae of TBI may predispose some individuals to violence (Miller, 1999).

TBIs, particularly mild and moderate, to which victims of intimate partner violence may be more susceptible, are often localized in the orbito-frontal and temporal polar zones of the brain (Zappalà, Thiebaut de Schotten, & Eslinger, 2012), areas associated with increased aggression (Daoust, Loper, Magaletta, & Diamond, 2006). Meta-analyses have demonstrated a medium effect size (d = 0.47; *95%CI* = 0.42-0.51; p<0.0001) for the relationship between antisocial behavior and neuropsychological measures of executive functioning (Morgan & Lilienfeld, 2000; Ogilvie, Stewart, Chan, & Shum, 2011). However, this area of neuropsychological research is marred by methodological problems, rendering findings inconclusive. Comparing aggressive with non-aggressive individuals with severe TBI (Greve et al., 2001) and mild-severe ABI (Kerr, Oram, Tinson, & Shum, 2011), some research has demonstrated no significant cognitive (Greve et al., 2001) or injury-related differences (Kerr et al., 2011). However, another study of severely injured individuals found significantly greater deficits in verbal memory and visuo-perceptual skills in the aggressive group than in the non-aggressive group (Wood & Liossi, 2006).

1.3. TBI and violence in females

In the UK in 2011, 34% of arrested females and 31% of males were arrested for "violence against the person"(Ministry of Justice, 2011). Similarities in prevalence across gender challenge the stereotype that violence is a male issue. Within 12 months of release from prison, 17.8% of females reoffend across offense types (e.g., violence, theft, drug offenses) (Ministry of Justice, 2013). Despite these figures, female offenders are a relatively understudied population with a research gender bias favoring males.

No large community-based epidemiological study has explored gender differences in the relationship between violence and TBI, despite reported gender differences in the presentation of offenders such as psychiatric comorbidity (Zlotnick et al., 2008), the

dominance of socio-economic and child-raising risk factors for females, and parental characteristics for males (Farrington, Painter, & Britain, 2004). The Swedish population study controlled for gender through matching, rather than including it in the stratified analyses (Fazel et al., 2011). A recent report commissioned by the Barrow Cadbury Trust (an independent, charitable foundation in the UK) emphasized the need for research examining the causes and consequences of TBI in female offenders specifically (Williams, 2012).

Although females have a lower recorded prevalence of offending than males, females who perpetrate offenses are more likely than males to be experiencing a mental illness (Butler, Allnutt, Cain, Owens, & Muller, 2005). Rao et al. (2009), comparing individuals with and without verbal aggression post-TBI, found that new-onset major depression increased the risk of aggression eightfold for females with a TBI. Females aged 25-39 years and with a mental illness demonstrate a population attributable risk-fraction of 14% in comparison to 6.7% of males; increasing to 19% for females and 7.3% for males over the age of 40 (Fazel & Grann, 2006). The issue of circular causality in the relationship between TBI and violent behaviors has been raised (Timonen et al., 2002), in that there are multiple associations between violence and TBI and an array of other variables, such as psychiatric comorbidities, that make it difficult to establish a clear causal pathway.

A meta-analysis of TBI in offender populations (e.g., prisons, secure forensic psychiatric units) places prevalence at 60.25% (*95% CI*: 48-72%) (Shiroma, Ferguson, & Pickelsimer, 2010a). Shiroma et al. (2010a) revealed a male and female prevalence estimate of 64.41% (*95% CI*: 53.3 to 75.53%) and 69.98% (*95% CI*: 50.18-89.79%), respectively. Once TBI definition was limited to LOC, excluding milder TBIs, males demonstrated a higher prevalence than females (59.31% vs. 55.28%). This decrease in prevalence once limited to LOC may suggest higher prevalence of mild TBIs specifically in females.

Research examining a heterogeneous population of ABI, as opposed to TBI, demonstrate female prisoners with ABI have significantly different cognitive impairments than males with ABI, performing worse on perceptual and spatial ability, complex visual memory, and spatial working memory (Jackson & Hardy, 2011). In comparison to females without ABI, females with ABI demonstrated cognitive difficulties, including significantly poorer performance on tests of perceptual, intellectual, and executive functions; complex processing speed and working memory (Jackson & Hardy, 2011). As violent and non-violent offenders were not separated it is not possible to discuss the neuropsychological relationship to violent behavior specifically.

In summary, the development of an understanding of the relationship between TBI and violence in females is confounded by differing definitions of TBI and violence, populations sampled, insufficient investigation of females specifically, and absence of gender specific data. This identifies a need for existing literature to be synthesized in a coherent manner to provide direction for future research which can inform intervention and management strategies in prison services and clinical practice. This systematic review aims to answer the question: What is the strength of empirical evidence indicating a relationship between TBI in females and violent behavior?

2. **Method**

2.1. Selection of studies

The method for conducting this systematic review was guided by the Preferred Reporting Items for Systematic reviews and Meta-analyses (PRISMA) Statement (Moher, Liberati, Tetzlaff, & Altman, 2009).

A literature search of three psychological and medical electronic bibliographic databases was conducted, namely PsycINFO, PubMed, and Scopus. Date range searched within the databases was from first available (PsycINFO 1806; PubMed 1948; 1823 Scopus) to February 2013. Title search terms included those pertaining to: TBI (i) 'brain injury' OR 'head injury'; violent behavior (ii) viole* OR offend* OR forensic OR aggress* OR prison*. Titles, abstracts, and key words were searched for terms pertaining to female sex (iii) sex OR gender OR female OR women. Figure 1 outlines the flow of studies through the search process.

Insert Figure 1 about here

Abstracts and titles of identified studies were read to determine if they met the following inclusion criteria:

- Original systematic empirical published research presenting data relating to the association between physical violence, physical aggression, or violent crime and TBI in female populations, with females as perpetrators rather than victims.
- Verbal aggression and threats were included for inpatient studies only, as these behaviors may be unreliable and difficult to measure outside inpatient settings (Monahan et al., 2001). Verbal incidents in inpatient settings may represent an increased risk of physical violence and demonstrate the same underlying mechanisms of physical violence due to the restrictive nature of the environment which prevents verbal incidents from escalating.
- The article was written in English.
- Studies of populations under 18years were included but examined separately from studies of adults.
- Mixed-sex studies were included where female data was separated for TBI and violence variables. Only published data were extracted, as failure to report gender-specific data is

evidence of the gender bias and selective reporting in this area and a limitation of many of the published studies.

This process yielded six empirical papers which are presented in the following sections: cross-sectional studies investigating the relationship between violence and TBI in females; case-control studies comparing groups of females with violent behaviors and controls without a violent conviction; longitudinal studies of violence and TBI in females. To explore how these studies have contributed to key research questions, sub-sections are presented discussing the evidence of the strength of the relationship between violence and TBI in females, and where on the causal pathway variables may lie in exploring the relationship between violence and TBI in women.

2.2. Quality assessment

Due to the non-experimental nature of the data and the absence of a preferred tool for evaluating such research (Jarde, Losilla, & Vives, 2012), an adaptation of King et al.'s (2008) method for assessing the quality of non-experimental studies was used (Table 1). It is based on the Cochrane Handbook's general guidance and quality indicators (2 indicating higher quality than 1) for non-experimental studies. Factors examined were: sampling (non-random = 1, random = 2); representativeness (response rates <60% = 1, ≥60% = 2); population definition (selected sample e.g., prison = 1, general population = 2); and sample size (<100 females with TBI = 1, >100 females with TBI = 2).

Insert Table 1 about here

2.3. Data Analysis

Due to the heterogeneity of the available research designs and quality, it was neither feasible nor appropriate to conduct a formal meta-analysis (The Cochrane Collaboration, 2011). Therefore, a narrative systematic review was conducted.

3. Results

3.1. Sample

Screening titles and abstracts demonstrated the poor gender reporting among studies, with many abstracts failing to report sample sex. The most common reason for exclusion of studies (*n*=54) was having male-only samples or failing to separate data by gender for relevant variables, demonstrating the substantial male gender bias. Other papers did not provide violence specific outcomes (e.g., they presented variables that did not separate physical violence from other forms or did not separate violent offenders from non-violent (*n*= 17). This process yielded six studies, of which two were cross-sectional designs, one was a case-control and three were longitudinal.

The following sections will discuss findings on the relationship between violence and TBI in females, possible variables that may sit on the causal pathway and methodological difficulties with these papers which can inform future research.

3.2. Summary of findings for a relationship between TBI and violence in females

Key methodological characteristics of the studies reviewed are summarized in Table 2. Overall, three of the six studies (Brewer-Smyth & Burgess, 2008; Brewer-Smyth, Burgess, & Shults, 2004; Shiroma et al., 2010b) provided evidence of a relationship between TBI and violence in females, specifically. The remaining three (Baguley, Cooper, & Felmingham, 2006; Johansson, Jamora, Ruff, & Pack, 2008; Stoddard & Zimmerman, 2011) found no

significant gender differences between levels of post-TBI violence, suggesting females may exhibit similar levels as males.

Insert Table 2 about here

Two studies were cross-sectional. Johansson, Jamora, Ruff, and Pack (2008) explored factors associated with aggression in TBI, including gender in their analysis, suggesting that females demonstrate similar levels of post-TBI physical aggression as males. Forty percent of females and 32.5% of males reported overt physical aggression; however, no statistically significant relationship was found between gender and physical aggression (r= 0.14, p> 0.05). Brewer-Smyth and Burgess (2008) examined whether childhood familial sexual abuse was related to increased neurological histories, including TBI. Results suggested that females who experienced familial childhood abuse had more TBIs (*OR* = 1.49, p = 0.01) and were convicted of more violent crimes (*OR* = 1.67, p = 0.05) than those not abused. However, it was not reported whether TBI occurred before or after the abuse. Brewer-Smyth et al.'s (2004) study was the only case-control study which met inclusion criteria. Their objective was to examine the relationship between basal resting salivary cortisol levels, abuse history, neurological history, and violent crime in females. Results found that among female offenders with TBI (prevalence of 42%), those with convictions for violence had significantly more TBIs than females offenders without convictions for violence (56% vs. 38%), and the odds of having a conviction for violence increased with each TBI (*OR* = 1.45, p = 0.12). 'Other neurologic history', consisting of TBI without LOC and sensory abnormalities, was not significantly different between violent and non-violent offenders (48% and 53%, respectively, p> .05). There was no significant difference between violent (4%) and non-violent (6%) offenders among those with severe brain injury, defined as a coma exceeding one day (p> .05). TBI with LOC was significantly higher in participants convicted of a violent crime (56% vs. 38%), with a dose-response effect in that for every additional TBI

with LOC the odds of being convicted of a violent crime in comparison to a non-violent crime increased significantly (*OR* = 1.451, *p* = 0.012). Brewer-Smyth et al. (2004) was the only study to examine the cumulative effects of recurrent TBIs on violence. Mean number of TBIs with LOC for those with a violent crime conviction was 1.75 (*SD* 2.9) in comparison to .74 (*SD* 1.19) among those convicted of a non-violent crime ($p< 0.05$). Brewer-Smyth et al. (2004) also compared female offenders with no known violent conviction, a current non-violent conviction but known past violent conviction, and those with current violent convictions. Female offenders with current violent convictions had significantly more TBIs per person (*M* = 1.75 *SD* 2.96, $p<0.05$) than the other two groups. Female offenders with past but not current violent convictions had fewer TBIs (*M* = 0.61 *SD* 1.17, $p<0.05$) than those with no known violent convictions (*M* = 0.86 *SD* 1.23, $p<0.05$), attributed to poor recording of criminal behavior.

Three longitudinal studies indicated that there were no significant gender differences in post-TBI violence, with females just as susceptible to post-TBI violence as males. Shiroma et al. (2010b) used a prospective cohort design, retrospectively gathering data on TBI over 11 years (1996-2007), while prospectively measuring in-prison behavioral infractions. The aim was to compare the in-prison behavioral infraction rate in prisoners with and without a history of TBI. Results demonstrated that prisoners with TBI had fewer convictions for violence (females without TBI 31% vs. 20% with TBI, *p* = 0.03) and infractions (females without TBI 34% vs. 24% with TBI, no *p* value reported). However, after controlling for age, violent crime conviction, prior criminal history, security level, sentence length, and race, females with TBI had an increased rate of infractions over those with no TBI (violent infraction rate of 144%; TBI *M* = 1.20 *SD* 1.27; no TBI *M* = 0.68 *SD*0.76; *RR* = 2.44, 95% *CI*: 1.45-4.12). The significantly increased rate of behavioral infractions in female prisoners with a TBI was found to a lesser extent in the male sample (TBI *M* = 1.04 *SD* 1.50; no TBI *M* = 0.81 *SD*

1.18; *RR* 1.86, 95% *CI:* 1.54-2.24). However, Shiroma et al. (2010b) did not explore gender differences in relation to TBI prevalence and frequency of behavioral infractions. An analysis of the number and/or severity of TBIs and relationship to violence was not conducted. Non-violent infractions did not have a significantly increased likelihood in females with TBI (TBI *M* = 1.09 *SD* 1.47; no TBI *M* = 0.91 *SD* 0.95; *RR* = 0.62; 95% *CI*: 0.36-1.08). The prevalence of violent behavioral infractions and convictions for violence among the female prisoners in the Shiroma et al. (2010b) study suggests that although fewer females with a conviction for violence had a TBI, those with TBI have a higher prevalence of violent behavior in prison. Therefore, violent crime conviction may not be a reliable surrogate measure of physical violence.

Similarly to Johansson et al. (2008), Baguley, Cooper, and Felmingham's (2006) findings suggest that females with TBI exhibit comparable prevalence of post-TBI violence to males. Their retrospective cohort study aimed to assess prevalence and predictors of aggressive behavior. There was no significant difference in post-TBI aggression between males and females at any of the time-points, namely 6, 24 and 60 months post-discharge (statistical data were not reported for time-points). Stoddard and Zimmerman's (2011) high school cohort study which aimed to examine differences in interpersonal violence among participants with and without a TBI, also suggests that females exhibit similar levels of post-TBI violence to males. Multivariate regression analyses demonstrated that TBI occurring during or before high school years was not predictive of violent behavior in young adulthood (β = 0.08, p>0.05) when previous violence was included (β = 0.36, p<0.001). The effect of gender was small (β = -0.08, p<0.05), suggesting that violence risk is similar across both genders once past violence is accounted for. When TBI was restricted to TBI acquired in young adulthood, TBI predicted violence (β = 1.07, p<0.001). Once previous violence and risk behaviors, such as alcohol and marijuana use, delinquency, and violence observation were added to the

model, gender was not significant (β = -0.03, p>0.05). The non-significant results in these studies may be due to methodological limitations or demonstrate that females exhibit similar levels of post-TBI violence to males.

3.3. Possible variables on the causal pathway between TBI and violence in females

While it is not possible to determine causality in cross-sectional study designs, they can provide insight into variables that may have an impact on the causal pathway. Johansson et al. (2008) found that groups with higher aggression demonstrated significantly elevated depression and PTSD on subscales of the Ruff Neurobehavioral Inventory. Similarly, Baguley et al. (2006) using the BDI, found depression to be a significant predictor of aggression across their five year follow-up period, accounting for 24.9% (p<0.001) of the variance in the aggression score at 24 months and 15.9% (p = 0.002) at 60 months. Brewer-Smyth et al. (2004) found that although depression scores were not significantly different between violent and non-violent female offenders using the Beck Depression Inventory-II (BDI II; Beck, Steer, & Brown, 1996), those with convictions for violence had significantly increased odds of suicide attempts (*OR* = 1.249, p = 0.026). Brewer-Smyth et al. (2004) did not attempt to explain this. Current depression at one time point as measured by the BDI-II may not have been a significant predictor of violence; however, if suicide attempts are used as a proxy measure of lifetime depression, then results suggest that this variable may be on the causal pathway.

In the Brewer-Smyth and Burgess (2008) study it was unclear whether TBI was independently related to violence and the temporal sequence in relation to abuse. Specifically, childhood familial abuse may be a confounder, a moderator, or a mediator between TBI and violence. This was not explored within the study, but the question lends itself to consideration in future studies. Brewer-Smyth et al.'s (2004) results lend support to the role of trauma in

the relationship. Most TBIs were acquired through violence perpetrated against the participants or through high-risk behaviors, such as substance use. However, the authors did not provide figures to distinguish between the relative strength of these two factors. Low morning cortisol levels and decreased diurnal variation, which the authors posit is related to chronic stress associated with emotional and physical trauma, were significantly lower for those with a violent conviction (M = 0.297 SD 0.23 vs. M = 0.446 SD 0.47, $p \leq 0.05$, OR = 0.036, p = 0.17; M = 0.117 SD 0.22 vs. 0.281 SD 0.22, $p \leq 0.05$). Neurologic examination found TBIs existed predominantly in the frontal-temporal region. Participants with violent crime convictions had significantly more hospital treatments for abuse-related injuries than those with non-violent convictions (M = 2.15 SD 3.84 vs. M = 0.94 SD 2.02, p<0.05) and participants with violent convictions had experienced abuse significantly more recently than their non-violent counterparts (M = 3.83 SD 4.15 years vs. M = 9.77 SD 9.96 years, p<0.05). The available literature suggests that relationships exist between TBI and violence (Rosenbaum et al., 1994) and abuse victimization and violence perpetration (Van Dorn, Volavka, & Johnson, 2011, 1 June). That TBI alone does not always lead to violence suggests that other variables, such as recency of abuse, should be considered for moderator effects. Furthermore, the effects of incarceration in prison should also be considered. Shiroma et al. (2010b) found that incarceration in prison reduced TBI incidence, a stronger finding among female rather than male prisoners (annual incidence rate while not incarcerated of 83.95 per 10000 in males and 79.02 per 10000 in females; 11.91 per 10000 in males and 1.89 per 10000 in females while incarcerated). The community/incarceration gender difference in prevalence of TBI incidence might suggest that female participants were living in harmful environments prior to incarceration and indicates a possible link between TBI incidence and risk of intimate partner violence, so supporting the idea that intimate partner violence or other environment risk factors influence the causal pathway between TBI and violence in females.

3.4. Critical evaluation of sampling and design

None of the cross-sectional study designs allow for causal conclusions. Johansson et al.'s (2008) results demonstrating similar levels of post-TBI physical aggression across males and females ($r = 0.14$, $p>0.05$) may be attributable to methodological flaws and being underpowered, which will be discussed further in the results. Brewer-Smyth and Burgess (2008) found a significant relationship between childhood familial abuse, TBI and violence (OR = 1.67, $p = 0.05$); however, it suggests that the relationship is more complex than TBI causing violence.

There are no community-based epidemiological designs among the six studies reviewed. Of the two cross-sectional studies, one was conducted with a prison population (Brewer-Smyth & Burgess, 2008) and the other within a clinical population (Johansson et al., 2008). Brewer-Smyth and Burgess (2008) described their study design as cross-sectional in the abstract and as a 'modified case-control design' (p.167) in the method section. A defining characteristic of a case-control study is that cases and controls are matched on the basis of outcome (Mann, 2003), whereas Brewer-Smyth and Burgess (2008) matched on exposure to familial childhood sexual abuse, making their design cross-sectional. Inconsistent reporting of study designs in the literature is problematic. Brewer-Smyth et al.'s (2004) prison data appeared to be from the same project as the Brewer-Smyth and Burgess'(2008) cross-sectional study. Cases and controls were selected on the basis of the outcome of committing a violent crime. The cross-sectional design (Brewer-Smyth & Burgess, 2008) stated participants were randomly recruited; but this is unclear in the case-control design, which appeared to recruit a convenience sample. While Brewer-Smyth et al.'s (2004) case-control study provides some thought-provoking results on the relationship between TBI and violence in females, it is impossible to ascertain the directionality of the association. Of the three longitudinal studies reviewed, one recruited from a prison, one from a clinical setting, and one from a high-school

population. Results from Stoddard and Zimmerman (2011), in particular, must be interpreted with caution due to methodological and reporting difficulties. The exact age at which participants were recruited was not reported, only that the study examined from mid-adolescence to young adulthood. Data were collected over eight time-points, including four consecutive high school years, and the second through to fifth years after high-school. TBI was assessed at post-high school time-points. Throughout the paper, reporting is ambiguous and some statistical and methodological details (e.g., coding of variables and confidence intervals) were lacking, which renders study replication and interpretation problematic.

Generalizability and representativeness are limited for all studies. Clinical samples, such as in the Johansson et al. (2008) study from an outpatient neuropsychology service and Baguley, Cooper, and Felmingham's (2006) sample from a tertiary brain injury rehabilitation hospital, may exclude milder TBIs and vulnerable socio-economically deprived demographic groups (Oddy, Moir, Fortescue, & Chadwick, 2012). For instance, 68% of Baguley et al.'s (2006) participants fell into the severe range on the GCS. Participants with inadequate English proficiency and pre-morbid neurological and/or psychiatric history were also excluded by Johansson et al. (2008). Most participants were in litigation, which can distort data (e.g., by increasing anxiety or malingering (King, 1997)). As individuals with prior neurological histories were excluded, the impact of multiple TBIs on aggression could not be examined. Although Brewer-Smyth and Burgess' (2008) study is limited in generalizability due to the prison sample, it provides a useful overview of a vulnerable population with reports of as many as 75% of incarcerated females experiencing severe physical violence by partners (Browne, Miller, & Maguin, 1999). Baguley et al. (2006) experienced attrition during the follow-up period, with the initial sample composed of 228 participants and only 67 partaking in the 60 month follow-up.

Quality criteria for the selected studies (Table 1) demonstrate the paucity of research conducted with females with head injury, with no study obtaining a female TBI sample of over 100. Brewer-Smyth and Burgess (2008) and Brewer-Smyth et al. (2004) were the only studies to report power calculations. Without reference to power calculations it is not possible to conclude that sample sizes were sufficient to detect significant results. The absence of non-TBI control groups also makes interpretation of results difficult in the studies reviewed.

3.5. Critical evaluation of measurement

Variability in operationalization and measurement of variables makes comparison across studies difficult. Johansson et al. (2008) used aggression as a surrogate measure of violence. All studies relied heavily on self-report measures across variables, increasing the likelihood of recall bias. Recall bias has been reported in non-TBI studies (Houtveen & Oei, 2007) and may be more pronounced in individuals with cognitive impairment. Johansson et al. (2008) used a self-report measure of aggression, but corroboration with family reports was only possible in 16% of cases. The authors' clinical impression was that many participants under-reported aggression due to embarrassment and stigma. Stoddard and Zimmerman (2011) measured interpersonal violence using a 4-item scale. Cronbach's alpha ranged from 0.62-0.76, suggesting questionable internal consistency (Carmines & Zeller, 1979; Nunnally, 1978). Measurement of TBI was also problematic. Stoddard and Zimmerman (2011) relied solely on self-report for assessment of TBI and they did not report whether participants' responses on TBI were consistent throughout the time-points. Considering that their most significant association was between proximal TBIs and violence, it is plausible that this finding might be a consequence of recall bias. Both Johansson et al. (2008) and Shiroma et al. (2010b) used medical records, which are likely to underestimate TBI prevalence. Brewer-Smyth and Burgess (2008) defined TBI dichotomously as physical head trauma resulting in LOC and did not examine severity, which risks excluding mild recurrent TBIs. As

demonstrated by Browne (1999), while 75% of incarcerated females experienced physical violence, only 22% reported concussions, indicating the risk of missing more subtle neurological impairment. Brewer-Smyth and Burgess (2008) corroborated reports with criminal and medical records where possible, as well as physical examination. Baguley et al. (2006) mentioned that injury pattern as seen on computed tomography (CT) was not significant in predicting aggression; however, they did not provide information as to how injury pattern was evaluated. Furthermore, mild TBI often does not result in any abnormalities in CT scans (Haydel et al., 2000). Three studies (Brewer-Smyth & Burgess, 2008; Brewer-Smyth et al., 2004; Shiroma et al., 2010b) operationalized violent behavior as violent crime conviction defined by the criminal justice system. Although this is a common measure in violence research, it is likely an underestimate of violent behavior as it relies on an individual receiving a conviction. It may also be problematic when comparing across jurisdictions.

4. **Discussion**

Overall, three of the six studies (Brewer-Smyth & Burgess, 2008; Brewer-Smyth et al., 2004; Shiroma et al., 2010b) provided some evidence of a positive relationship between TBI and violence in females in comparison to females without TBI. The remaining three studies (Baguley et al., 2006; Johansson et al., 2008; Stoddard & Zimmerman, 2011) found no significant gender differences between levels of post-TBI violence, suggesting females exhibit similar levels to males. However, all of these studies have substantial methodological limitations and none was designed specifically to determine the nature of the relationship between TBI and violence in females. Therefore, the main conclusion is that there is insufficient evidence regarding a relationship between TBI and violence in females and that research addressing this question presents with methodological limitations. However, the

studies reviewed herein present critical points that suggest that further exploration on the relationship between TBI and violence among females is warranted.

Brewer-Smyth et al.'s (2004) study was the only one to examine the cumulative effects of recurrent TBIs on violence and found some evidence for a dose-response effect between number of TBIs and violence. This did not include mild TBI. Brewer-Smyth et al.'s (2004) findings are consistent with previous research which has found reported prevalence rates of multiple TBIs in female offenders ranging from 35-48% (Ferguson, Pickelsimer, Corrigan, Bogner, & Wald, 2012). Individuals who sustain multiple mild TBIs can have similar cognitive and behavioral profiles to those with more severe TBI (Diamond et al., 2007). Multiple mild TBIs have also been related to increased likelihood of post-concussive syndrome (Miller, Ivins, & Schwab, 2013) and chronic traumatic encephalopathy (Kelly, Amerson, & Barth, 2012). Brewer-Smyth et al. (2004) found that TBIs most frequently affected the fronto-temporal region which, as discussed previously, has been related to post-TBI aggression in the literature (Daoust et al., 2006).

The studies reviewed also suggest that physical and sexual abuse throughout the lifespan may play a role in the relationship between TBI and violence in females (Brewer-Smyth & Burgess, 2008; Brewer-Smyth et al., 2004; Shiroma et al., 2010b). Browne et al.'s (1999) study of victimization experiences and criminal behavior demonstrated that many female prisoners have experienced abuse from a young age. Childhood victimization strongly predicts victimization in adulthood (Browne et al., 1999) and adult victimization in turn increases the risk of TBI (Kwako et al., 2011), which may lead to increased violent behavior (Ogilvie et al., 2011). Therefore, childhood abuse may be an important potential moderator of the association between TBI and violence. This is consistent with Brewer-Smyth and Burgess' (2008) findings of increased childhood family sexual abuse in those with more TBIs and violent crime convictions.

Research has demonstrated that increased post-TBI aggression is related to perpetration of intimate partner violence in males (Rosenbaum et al., 1994). It is unclear if aggression after TBI is related to being a victim of intimate partner violence. None of the six studies reviewed provided data separated by gender for mechanism of injury. However, Shiroma et al.'s (2010b) finding of decreased likelihood of suffering a TBI while incarcerated lends some tentative support for the hypothesis that intimate partner violence in females is a key injury mechanism in females exhibiting violent behavior, as does Brewer-Smyth et al.'s (2004) findings of increased recency and hospitalizations for abuse-related injuries in those with violent crime convictions.

Depression appears to be an important factor in moderating violence as an outcome post-TBI (Ferguson et al., 2012; Kelly et al., 2012; Miller et al., 2013) and PTSD may also be significant (Johansson et al., 2008). It is unclear whether there are gender differences in the impact of psychiatric comorbidities; and a variety of psychiatric comorbidities have been reported in people with TBI and a history of violence in other literature (Colantonio, Stamenova, Abramowitz, Clarke, & Christensen, 2007). Rao et al. (2009) found verbal aggression was associated with post-TBI depression. Overall, the studies reviewed suggest that TBI may be one of many factors that contribute to violence in females.

4.1. Methodological considerations

The studies reviewed had a number of limitations. With regards to sampling, none of the studies were generalizable as they were conducted within selected populations, and five were conducted in the US. No study had a sample with over 100 females with TBI, making it difficult to have sufficient power. However, the studies that included mixed-sex samples should be commended for reporting gender specific data. Of the six studies, only two, which came from the same original data-set, examined females specifically (Brewer-Smyth &

Burgess, 2008; Brewer-Smyth et al., 2004), demonstrating the paucity of this type of research in females.

There were limitations regarding the definitions and instruments used to measure TBI and violence. These limitations are not specific to female studies and have been reported in research reviewing the relationship between TBI and violence irrespective of gender (Fazel, Philipson, Gardiner, Merritt, & Grann, 2009). All of the studies relied on LOC as an indicator of TBI and only Brewer-Smyth et al. (Brewer-Smyth et al., 2004) attempted to examine the role of injury severity in the relationship. As discussed previously, females may be at a higher risk of recurrent mild TBIs and have a higher prevalence of TBI when not limited to LOC (Shiroma et al., 2010a). Milder TBIs should not be dismissed, considering the possible impact of mild recurrent TBIs (Diamond et al., 2007). However, Brewer-Smyth et al. (2004) did not find evidence supporting a relationship between violence and TBI without LOC in females.

Only two (Brewer-Smyth & Burgess, 2008; Brewer-Smyth et al., 2004) studies used a combination of methods for identifying TBI, corroborating self-report with medical and criminal records, as well as physical examination. Reliance on medical records risks under-identification of TBI, with reports of up to 43% of individuals with a TBI not seeking medical attention (Setnik & Bazarian, 2007). This is further compounded by risk of errors and insufficient recording (Horwitz & Yu, 1984). Stoddard and Zimmerman (2011) relied solely on self-report. Reliance on self-report is problematic with brief scales and surveys such as that used by Stoddard and Zimmerman (2011) risking failure to detect all but the most recent or severe TBIs (Corrigan et al., 2010). None of the reported studies used neuropsychological assessment, which is considered the gold-standard of examining the sequelae of TBI (Shiroma et al., 2010a). Furthermore, identifying TBI by simply using LOC does not assist in determining the prevalence of ongoing sequelae. This is particularly

important in forensic contexts considering research has demonstrated that females offenders have more ongoing symptoms post-TBI than male offenders, including difficulties controlling substance use, temper, and emotions (Ferguson et al., 2012).

Three studies relied on violent convictions as a measure of violent behavior (Brewer-Smyth & Burgess, 2008; Brewer-Smyth et al., 2004; Shiroma et al., 2010b). Comparisons of prevalence of convictions for violent crime are limited by differences in definition across jurisdictions and legal processes therein. For example, a successful defense might reduce the conviction on contextual evidence for an objectively more serious behavioral offense (Shiroma et al., 2010b). Furthermore, as identified in the mental health literature (Hodgins, 1998), people with TBI may be at risk of a greater number of convictions due to ease of detection related to cognitive difficulties. Only Brewer-Smyth et al. (2004) included an analysis of past violent convictions, alongside current violent convictions, which suggested that current violent crime may not be a reliable surrogate for violence. The remaining three studies used self-report measures of violence and physical aggression (Baguley et al., 2006; Johansson et al., 2008; Stoddard & Zimmerman, 2011). Johansson et al. (2008) supplemented clinical ratings with a valid self-report scale. However, Stoddard and Zimmerman (2011) used a one-item rating scale with questionable reliability. Baguley et al. (2006) attempted to control for bias with the Overt Aggression Scale (OAS) by incorporating informant ratings (Yudofsky, Silver, Jackson, Endicott, & Williams, 1986). Violent behavior outside of current convictions needs to be accounted for, as well as managing the bias of self-report measures. Ideally, this would be achieved using resource intensive methodologies such as those in the MacArthur study, combining self-report, informant-report, arrest, and hospitalization records (Monahan et al., 2001).

Other measures of relevant variables also differed between studies. Overall, across studies there was insufficient investigation and methodological rigor in examining the question of

relevance to this review, the association between TBI and violence in females and the potential confounders, mediators, and moderators of that relationship.

4.2. Future research

Research is urgently needed to build upon the studies reviewed and improve the evidence-base on TBI and violence with a specific focus on females. A previous meta-analysis has already identified the scarcity of studies on general female populations (Farace & Alves, 2000). Yet, this research need appears to have been relatively ignored. This review highlights that gender bias still prevails in the field, specifically in forensic contexts. The need for quality epidemiological research examining the relationship between TBI and violence in females using appropriate valid measures would ideally be met by a longitudinal birth cohort study, such as the Swedish population study (Fazel et al., 2011), with an examination of gender-specific data. Where studies do include females in their samples, gender-separated data and analyses should be provided when sample size allows. Observational research needs to ensure that reporting standards reach a high quality, using guidelines such as Strengthening the Reporting of Observational Studies in Epidemiology (STROBE; von Elm et al., 2007). This will facilitate a meta-analysis of the evidence on the relationship between TBI and violence in females when there are sufficient studies. Finally, researchers and clinicians in both the fields of TBI and forensic mental health would benefit from agreed measures of both violence and TBI to facilitate comparison between studies.

To facilitate future research and support clinical practice, a screen for TBI validated in females needs to be available. Currently, many studies rely on instruments developed for specific individual studies, with little consideration of reliability and validity (Diamond et al., 2007). There are currently two published valid screening tools developed for use with prisoners, the Traumatic Brain Injury Questionnaire (TBIQ; Diamond et al., 2007) and the

Ohio State University TBI Identification Method (OSU TBI-ID; Bogner & Corrigan, 2009). The validity and reliability of the TBIQ has been explored in male and female prisoners in the US (Diamond et al., 2007). And the validity and reliability of the OSU TBI-ID has been explored in males and females with a history of substance use (Corrigan & Bogner, 2007), as well as a prison population (Bogner & Corrigan, 2009). Future research should aim to extend the validity of such TBI screens, including to a female UK prison population. Indices on the OSU TBI-ID, which required an estimate of mild TBIs, relating to episodes such as intimate partner violence, were unreliable (Bogner & Corrigan, 2009). Therefore, this may not be appropriate for female prison populations. Also, the TBIQ has only been validated against short symptom rating scales. Extending validation of a TBI screen will enable researchers to determine the prevalence of TBI in other populations, including UK female offenders, which is currently unknown.

As indicated in Brewer-Smyth et al. (2004), future research needs to explore the impact of recurrent TBIs and how this compares to the neuropsychological profiles of more severe injuries. Research on neuropsychological profiles should also examine differences between those with reported violent behavior and those without violent behavior, particularly in females, considering the cognitive differences between male and female offenders with ABI discussed previously (Jackson & Hardy, 2011).

4.3. Clinical implications

Understanding the relationship between TBI and violence in females has a number of clinical implications. Without appropriate early intervention post-TBI, individuals may become involved in the criminal justice system (Brower & Price, 2001; deSouza, 2003; Greve et al., 2001; Kreutzer, Marwitz, & Witol, 1995; Kreutzer, Wehman, Harris, Burns, & Young, 1991; Miller, 1999; Simpson, Blaszczynski, & Hodgkinson, 1999). Once in custodial care,

individuals with TBI may be more difficult to rehabilitate and discharge, with services ill-equipped to address their needs. Hawley and Maden's (2003) study of TBI in a secure psychiatric unit indicated that 41.6% of service users had a history of TBI and were significantly more difficult to discharge into the community due to perceived risk of violence to others and self-harm. Research demonstrating increased disciplinary incidents in prisoners with TBI (Merbitz, Jain, Good, & Jain, 1995; Morrell, Merbitz, Jain, & Jain, 1998; Shiroma et al., 2010b) suggests they may also have greater difficulty adapting to prison life due to cognitive and behavioral sequelae. This has implications for engagement in the legal process, prison management and post-discharge and release pathways (Jackson & Hardy, 2011). Without adequate screening in female offenders, TBI is likely to go undetected and may impact on engagement in offender rehabilitation programs and the legal process (Jackson & Hardy, 2011). Officials within the criminal justice system may misinterpret behavior (Merbitz et al., 1995; Shiroma et al., 2010b). Furthermore, screening can provide a cost-effective way of determining who should be referred to more limited and expensive resources such as neuropsychologists or alternative care pathways such as secure psychiatric units. As demonstrated by Brewer-Smyth et al. (2004), female offenders with TBI often have had little if any access to neuropsychological interventions. Screening can demonstrate treatment needs, inform policy and support services in providing targeted adapted rehabilitation for this population. Under-identification may perpetuate inadequate resources, providing no incentive to fund appropriate interventions. Research in male prison populations is leading to increased resources, e.g., provision of a prison brain injury link-worker for individuals with TBI (Pitman, Haddlesey, Ramos, Oddy, & Fortescue, 2014). It could be argued that the next step for research and practice is to extend these developments to a female population.

Research suggests female offenders with cognitive difficulties may require bespoke management strategies (Jackson & Hardy, 2011). Without an understanding of the impact of

TBI on violence in females, offender rehabilitation programs are likely to have a limited effect on this population (Jackson & Hardy, 2011). Further research can inform rehabilitation programs, facilitate engagement, inform community placement (Hawley & Maden, 2003), and thereby reduce recidivism (León-Carrión & Ramos, 2003). This will inform staff training, ensuring staff working with these individuals understand presentations, are skilled in using adequate behavior management techniques and can make appropriate adaptations to service delivery (Jackson & Hardy, 2011; Merbitz et al., 1995; Morrell et al., 1998).

Given the complex relationship that TBI appears to have with psychiatric comorbidities (Rogers & Read, 2007; Silver et al., 2001; Timonen et al., 2002), this review highlights the need for services to address psychiatric comorbidities and adopt a multidisciplinary approach in individuals with TBI, rather than focusing on the TBI or violent behavior exclusively (Jackson & Hardy, 2011). Time spent in prison, away from risky environments (Shiroma et al., 2010b), may provide offenders and services with a valuable opportunity for individualized targeted interventions that may result in decreased victimization and recidivism (Browne et al., 1999). Finally, addressing these issues is vital in the context of women as primary carers to children, if we are to minimize the cycle of intergenerational abuse, TBI, and violence.

5. **Conclusions**

Although available studies support a positive relationship between violence and TBI in females, the strength of the evidence is poor considering methodological limitations and scarcity of research in this area. The studies reviewed suggest the relationship between TBI in females and violent behavior is complex, with many variables possibly impacting the causal pathway, including psychiatric comorbidities and history of abuse. The reviewed studies can inform future research and clinical practice.

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Figure 1. Selection of studies using PRISMA guidelines (Moher, Liberati, Tetzlaff, & Altman, 2009)

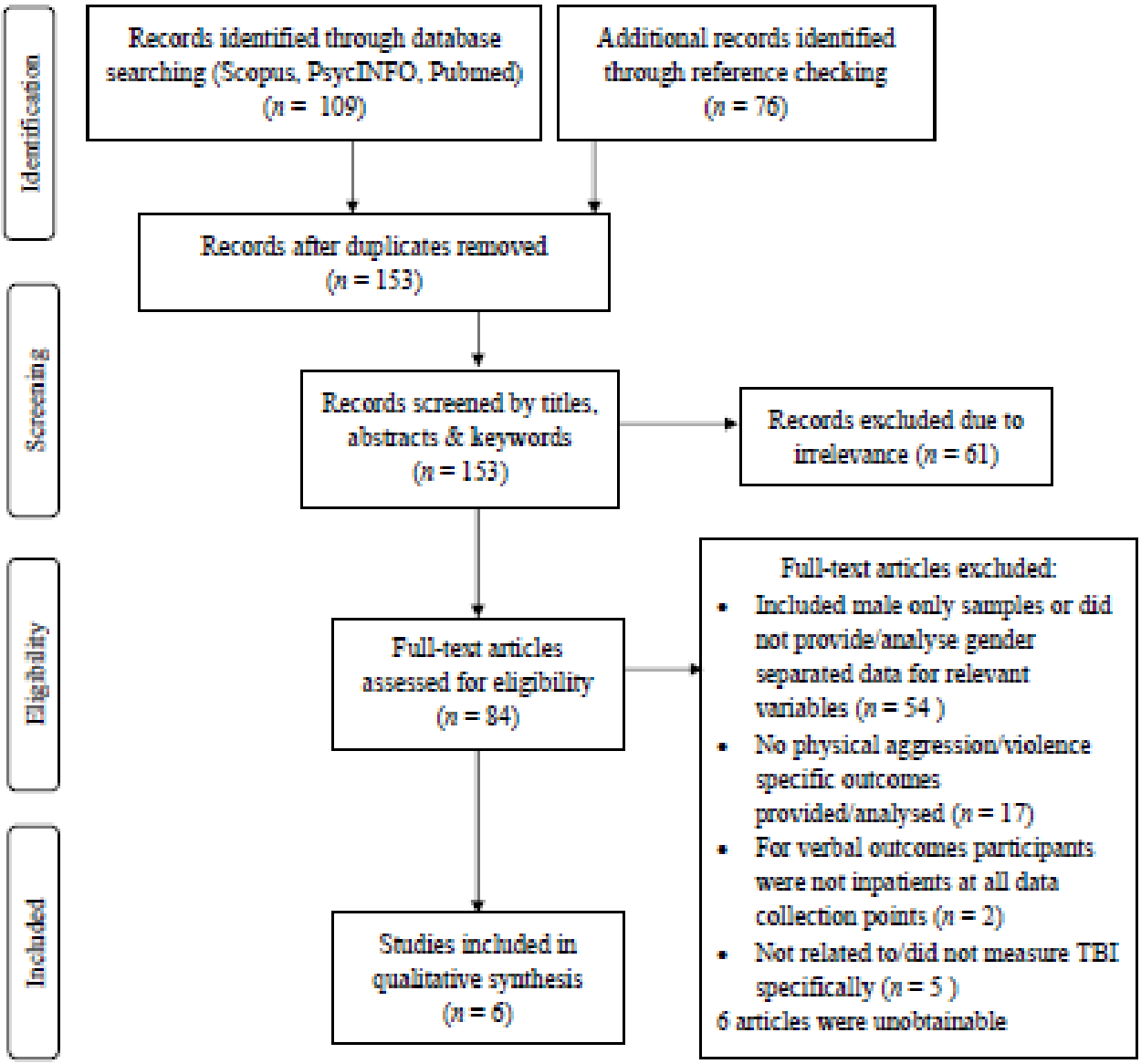

Table 1. Classification of quality indicators of studies included in the review

	Sampling 1= Non-random 2= Random	Participation rate 1= <60% 2= ≥60%	Population 1= Selected 2= General	Female sample size 1= <100 2= ≥100
Brewer-Smyth & Burgess (2008)	2	2	1	1
Shiroma et al. (2010b)	1	2	1	1
Johansson et al. (2008)	1	2	1	1
Baguley et al. (2006)	1	2	1	1
Brewer-Smyth et al. (2004)	1	2	1	1
Stoddard & Zimmerman (2011)	1	2	1	1

Table 2.Summary of reviewed studies

Cross-sectional studies							
Authors & Country	Sampling	Gender (M=male; F=female); age (mean years)	Participation rate	Violent behavior	Article quality score	TBI	Results
Brewer-Smyth & Burgess (2008) USA	Minimum and maximum security units of women's prisons	89F with no childhood family sexual abuse (34.59 years); 60F with childhood family sexual abuse (34.16 years)	81%	Criminal offences defined by criminal justice system	6/8	LOC	Females who experienced childhood family sexual abuse experienced more TBIs (OR = 1.49, p = 0.01) and were convicted of more violent crimes (OR = 1.67, p = 0.05)
Johansson et al. (2008) USA	Clinical sample of consecutive patients at an outpatient neuropsychology office	40M; 27F; Mean age for total sample was 40 years	65%	Anger severity rated by clinical interview on a four point ordinal scale. Points 3 and 4 indicate physical aggression; Anger and aggression scores from RNBI (Ruff & Hibbard, 2003) also obtained	5/8	GCS, LOC, PTA, focal neurological deficits, and neuro-imaging results	No significant relationship between gender and anger groups (r = 0.14, p> 0.05) or post-morbid RNBI anger score (t = -1.52, p> 0.05)

Case-control studies								
Author & Country	Sampling	Case gender (M=male; F=female); age (mean years)	Control gender (M=male; F=female); age (mean years)	Participation rate	Violent behavior	Article Quality Score	TBI	Results
Brewer-Smyth et al. (2004) USA	Convenience sample from minimum and maximum	27F (32.86 years)	86F (33.57 years)	81%	Crimes grouped as violent or non-violent based on criteria established	5/8	LOC	TBI significantly higher in females convicted of a violent in comparison to non-

	security units of women's prisons				in previous research (Volavka, 2002)		violent crime (OR = 1.45, p = 0.012).
Longitudinal studies							
Country & author	Sampling	Gender (M=male; F=female); age (mean years)	Participation rate	Violent behavior	Article Quality Score	TBI	Results
Shiroma et al. (2010b) USA	Inmates census sample from SCDS	1136M (median = 30 years)with TBI, 18962M without TBI (median = 33 years); 94F (median = 34 years) with TBI; 1418 without TBI (median = 36 years)	Complete histories available for 87% of sample	South Carolina state statute definition of violent vs. non-violent crime	5/8	Medically attended TBI using ICD-9-CM criteria	Higher proportion of current violent crime convictions (54% vs. 40% [p<0.0001] and 31% vs. 20%[p=0.03]) in males and females without TBI respectively; 25% and 18% of males and females with TBI respectively had violent infractions, in comparison to 30% and 18% of males and females without TBI respectively; compared to females without TBI, females with TBI had a significantly increased violent infraction rate (RR=2.44)
Baguley et al. (2006) Australia	Consecutive inpatients admitted to a tertiary hospital over 7 years	179M; 49F; Mean age for M and F combined was 34.3 at time of injury	71.5%	OAS (Yudofsky et al., 1986)	5/8	GCS; PTA; GOS	Gender not significantly associated with aggression at 6, 24 or 60 month follow-up (figures not provided)
Stoddard & Zimmerman (2011) USA	8 year cohort selected by grade point average to study youth at-risk of high school dropout (mid-adolescence to young adulthood)	425M; 425F	68%	Four-item scale of inter-personal violence	5/8	Concussion, skull fracture or LOC	Childhood TBI not predictive of violent behavior in adulthood (β = 0.08, p>0.05). Gender (β -0.08, p<0.05) and previous violence (β = 0.36, p<0.001) contribute significantly to model. TBI acquired in young adulthood predicted violence (β = 1.07, p<0.001), but gender did not make a significant contribution (β = -0.03, p>0.05)

Highlights

- We review research into the relationship between TBI and violence in females.
- Six papers met inclusion criteria, demonstrating the dearth of research in this area.
- Three studies suggested a positive relationship between violence and TBI in females.
- Three studies suggested females exhibit similar post-TBI violence to males.
- Psychiatric comorbidities and abuse may influence post-TBI violence in females.