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ABSTRACT

Objective: This study describes the association between lifetime traumatic brain injury (TBI) and attention deficit and hyperactivity disorder (ADHD) among Canadian adults.

Method: A cross-sectional sample of 3,993 Ontario adults aged 18 or older were surveyed by Computer Assisted Telephone Interviewing (CATI) throughout 2011 and 2012 as part of the CAMH Monitor, a rolling survey assessing the health, mental health and substance use of Ontario adults aged 18 and older. TBI was defined as trauma to the head that resulted in loss of consciousness for at least five minutes or overnight hospitalization. ADHD was measured by the 6-item ASRS screener for adult ADHD, and self-reported history of diagnosed ADHD.

Results: Among adults with a history of TBI, 6.6% (95% CI: 4.7, 9.4) screened ADHD positive, and 5.9% (95% CI: 3.6, 9.5) reported having been diagnosed with ADHD in their lifetime. Adults with lifetime TBI had significantly greater odds of scoring positive on the ADHD/ASRS screen (OR=2.49, 95% CI: 1.54, 4.04), and of reporting a history of diagnosed ADHD (OR=2.64, 95% CI: 1.40, 4.98) than without TBI, when holding values of sex, age, and education constant.

Conclusion: Significant positive associations between lifetime TBI and both current and past ADHD were observed among adults in this population. More research to understand these associations, and their significance for the etiology and management of TBI and ADHD, is needed.

KEYWORDS: Traumatic brain injury, attention deficit disorders, ADHD, anxiety, Ontario adults, population survey

INTRODUCTION

Traumatic brain injuries (TBI) are increasing in developed countries (Bowman et al., 2008; Coronado et al., 2011; Halstead & Walter, 2010; Ilie et al., 2013; Zernicke et al., 2007; Canadian Institute for Health Information, 2006). Team sports injuries (e.g., hockey, football) have been identified as the main source of TBI among youth, while falls and motor vehicle collisions are the main mechanisms of TBI among adults (Centre for Disease Control and Prevention, 2010; Coronado et al., 2011; Gilchrist, 2011; Ilie et al., 2013; 2015; Zernicke et al., 2007). TBI is a condition characterized by change in brain function that is caused by a hit or blow to the head by an external force (Menon et al., 2010). TBIs, including milder forms of the injury, may have disabling clinical outcomes (Coronado et al., 2011; Finselstein et al, 2006; Ilie et al., 2013; 2014a,b; 2015; Dematteo et al., 2010). The high prevalence and costs associated with TBI and TBI-related disability in Canada (over $7 billion), the US (over $60 billion), and worldwide have increased interest in TBI prevention (Canadian Institute for Health Information, 2006; Finselstein et al, 2006; Gilchrist, 2011; Gustavsson et al., 2011; Ilie et al., 2013; 2014a,b). The World Health Organization has predicted that by 2020 TBI will become the third world largest contributor of disease and disability following heart disease and depression (Thornhill et al., 2000).

Recent clinical studies implicate a relationship between attention-deficit/hyperactivity disorder (ADHD) and TBIs that were experienced during childhood (Eme, 2012). This may not be surprising since some of the most persistent consequences of TBI include ADHD-like symptoms, such as impairment in memory and attention, deficits in executive skills, issues related to speech articulation and decoding prosody, negative mood, and impulsiveness (Dooley et al., 2008; Jorge et al., 2004; Laird et al., 2005; Sharp et al, 2006; Williams et al.,

2010). ADHD is a pathophysiologically complex and heterogeneous psychiatric condition characterized by excessive inattention, hyperactivity, or impulsivity, either alone or in combination (Barkley, 2006). Neuropsychological research findings suggest that these behaviours result from an overall deficit in response inhibition, delay aversion, executive functioning (involving dysfunction of prefrontal regions, basal ganglia, the corpus callosum, and cerebellum) and motivation deficits that have been linked to the anterior cingulate cortex and associated mesolimbic dopamine circuits (Silvetti et al., 2013). ADHD was originally described among children and adolescents but is now recognized in the adult population as well (Keenan et al., 2008). Screening positive for ADHD has been associated with anxiety, depression, substance use and criminal offenses among adult males, and anxiety, depression, substance use and motor vehicle collision for adult females (Vingilis et al., 2015; Wickens et al., 2015).

ADHD has been identified both as a potential risk factor and consequence of TBI, but few population-based estimates of this association exist and they are, with one exception, exclusively based on samples of adolescents (Adeyemo et al., 2014; Babikian & Asarnow, 2009; Bonfield et al., 2013; Gerring et al, 1998; Hughes et al., 2013; McAllister, 2008; Orstein et al., 2013). In a recent study that examined disability following sports-related mild TBI among 48 children (aged 6 to 17) with ADHD and 45 children without ADHD (aged 5 to 16), researchers found that up to seven weeks after the head injury, youth with ADHD had significantly more disabilities than those who did not (Bonfield et al., 2013). Those with ADHD required significantly more assistance with daily activities, reported more behavioural problems, and required greater supervision to navigate stairs or get dressed compared with the non-ADHD youth (Bonfield et al., 2013). In another study involving 62,088 children registered

with the National Health Services in the UK, it was found that ADHD diagnosis before the age 10 was nearly twice as common among those who reported a history of head injury before the age of 10 (11.3%) compared to the uninjured group (6.3%) (Keenan et al., 2008).

To our knowledge, only one study examining the association between ADHD and TBI was based on adults (Adeyemo et al., 2014; Fann et al., 2004). This study examined whether psychiatric illness was more likely to occur following TBI compared to a group of healthy controls. Results showed a significant association between TBI and psychiatric illness, although ADHD was not significantly associated with TBI. However, results were deemed inconclusive by a meta-analysis published in 2014 because the sample, although large and based on hospitalized records (2817 controls, 803 TBI first, 620 unknown sequence of TBI, ADHD) showed a rate of ADHD in the control group (0.7%) that was not representative of the rate of ADHD expected in the general population (between 3.4% to 5%) suggesting that the overall results were not generalizable to the population and that more research needed to be undertaken (Adeyemo et al., 2014; Fann et al., 2004; Fayyad et al., 2007; Kessler et al., 2006).

The goal of our study is to describe population-based associations between lifetime TBI and ADHD in a population sample of adults. Age, education and gender were used as covariables in all analyses. While the causal order of the association cannot be addressed here, this study builds on the emerging evidence of the link between ADHA and TBI in the adult population (Adeyemo et al., 2014; Ilie et al., 2015, Ornstein et al., 2013).

METHODS

Our analytic sample is based on 3,993 adults cumulated from the Centre for Addiction and Mental Health's 2011 (n=1,999) and 2012 (n= 1,994) *CAMH Monitor*, a rolling quarterly random digit dial (RDD) telephone survey of Ontario adults aged 18 or older, and administered

by the Institute for Social Research at York University. Excluded from selection were adults who were phoneless, institutionalized, and unable to complete the interview in English. The multiyear design employed a stratified (6 regions by 2 cycles), two-stage (telephone number; household respondent) probability sample drawn quarterly through list assisted random digit dialing of listed and unlisted landline and cell telephone numbers, the latter of which has become a necessity in obtaining representative data (Hu et al., 2011). Each calendar year, the four quarterly samples are combined to provide a single annual dataset. Although 3,039 and 3030 adults were interviewed in 2011 and 2012 (response rate 51% for both cycles), our analysis is based on a random subsample of 1,999 and 1,994 respondents, respectively, who were designated to answer the TBI question as part of a health module of a 30 minute computer assisted telephone interview (CATI). A complete description of the survey and discussion of potential nonresponse bias is available on the *CAMH Monitor's* webpage (Ialomiteanu et al., 2011; 2013). All cycles of the CAMH Monitor survey were approved by the Research Ethics Committees of CAMH, St. Michael's Hospital, and York University, who administered the surveys. The study was conducted according to the principles expressed in the latest version of the Declaration of Helsinki. The mean age of the respondents who answered the TBI questions was 53.7 years (range: 18-97; SD=16.67) and 47.6% were male.

Measures

Traumatic Brain Injury

Head injuries sustained in one's lifetime were assessed by a single question prefaced as follows: *We are interested in any head injuries that resulted in you being unconscious (knocked out) for at least 5 minutes, or you had to stay in the hospital for at least one night because of it.* Respondents were then asked: *How many times, if ever in your life, have you had*

this type of head injury? Responses were binary coded to represent lifetime TBI (yes=1; no=0). This question, with an item response of 99.5%, is similar to those employed in recent studies of self-reported TBI (Anstein et al., 2004; Kuipers and Lancaster, 2000; Ilie et al., 2013; 2014a; Simpson and Tate, 2002; Tait et al., 2010) and is an operational definition used in several classification systems including DSM-IV, (Frances et al., 2000; Malec et al., 2007). While respondents were able to participate in regular adult activities, we cannot rule out the possibility of cognitive impairments affecting responses of TBI-injured adults. Nonetheless, we found that TBI adults were no more likely than non-TBI adults to assess the questionnaire as "difficult" (10.2%; 95%CI: 6.8%, 15.0% versus 6.7%; 95% CI: 5.4%, 8.2%; X^2 (1,1966)=5.04, P > 0.05). In a previous investigation involving Ontario adolescents, we observed that an item assessing self-reports of medically treated injuries in the past year was significantly and positively correlated with self-reports of TBI (Cramer's V = 0.21, $P < .001$).

ADHD screening instrument

We used both screener-based and summary item based methods to establish ADHD status. First, the adult ADHD Self-Report Scale-V1.1 (ASRS-V1.1), a module of the WHO Composite International Diagnostic Interview, was used to screen for ADHD [Kessler et al., 2005]. This 6-item, 5-point Likert screener has been demonstrated to be superior to the 18-item version of the DSM-IV ADHD screener on specificity (99.5% vs. 98.3%), sensitivity (68.7% vs. 56.3%), total classification accuracy (97.9% vs. 96.2%), and kappa (.76 vs. .58) [Able et al., 2007]. Those with scores greater than 13 (the validated cut score classifying positive cases) were classified as ADHD positive and coded as 1, or coded as 0 otherwise (Kessler et al., 2005; Able et al., 2007).

Lifetime ADHD diagnosis

Whether the individual had a history of ADHD diagnosis was assessed by the summary item 'Have you ever been diagnosed with Attention Deficit Disorder (ADD) or Attention Deficit Hyperactivity Disorder (ADHD) by a doctor or health care professional?' The variable was binary coded (yes=1; no=0). Lifetime ADHD was significantly and positively correlated with the ASRS-ADHD test (Cramer's V= 0.22, $P < .001$), providing evidence of concurrent validity.

Age, Sex and Education

Age was coded in 4 categories (18-29=1; 30-39=2; 40-49=3; 50 or older=4). Sex was binary coded (female=0, male=1). Highest education was coded in 4 categories (less than high school=1; completed high school=2; some post-secondary, college or university=3; university degree=4).

Analysis

To accommodate the complex survey data, variances were estimated using Taylor series linearization available in the Complex Sample module in SPSS V20.0 (Heeringa et al., 2010; Korn & Graubard, 1999). The final analyses were based on a design with 3,993 adults distributed among 12 strata (region × cycle). Design-based logistic regression assessed the association between lifetime TBI status (acquired vs. not acquired) and the two ADHD outcomes, while holding constant age, sex, and education. Results are based on valid responses; responses such as "do not know" and refusals were considered missing data and excluded from analyses listwise. To assess potential differential sex and age associations in the outcomes, TBI × sex, TBI x age, and TBI x sex x age interactions were introduced separately

to each of the two (adjusted) main-effects-only models listed in Table 2, and assessed with a differenced likelihood test.

RESULTS

Overall, 3.4% (95% CI: 2.7, 4.2) of the sample screened above the cutoff for positive ADHD status, 2.5% (95% CI: 1.9, 3.4) of the sample reported a history of ADHD in their lifetime, and 17.1% (95% CI: 15.6, 18.7) of the sample reported a history of TBI in their lifetime.

Table 1 presents the demographic characteristics and ADHD measures among adults who report lifetime TBI versus those who do not. The associations between history of TBI and scoring positive on the ADHD screener, as well as self-reported lifetime ADHD diagnosis were significant ($F(1,3806) = 15.64$, $P < 0.001$ and $F(1,3987) = 15.96$, $P < 0.001$, respectively). Firstly, among adults who reported a history of TBI, 6.6% (95% CI: 4.7, 9.4) screened positive for ADHD, currently, and 5.9% (95% CI: 3.6, 9.5) reported a history of ADHD diagnosis in their lifetime. Second, an estimated 66.6% (95% CI: 56.0, 75.7) of adults who screened positive for ADHD had no history of TBI, and 58.3% (95% CI: 42.9, 72.3) of the adults who reported a history of ADHD diagnosis in their lifetime did not report a history of TBI.

Table 2 shows logistic results modeling TBI status on scoring positive on the ADHD/ASRS and self-reported lifetime ADHD diagnosis. Ontario adults who sustained a lifetime TBI had greater odds of also screening positively for current ADHD and of reporting a lifetime diagnosis of ADHD (ORs=2.54 and 3.63, respectively).

When adjusting for the influence of age, sex, and education, adults with TBI still had more than twice the odds of a history of ADHD diagnosis (OR=2.64) and screening positively for ADHD (OR=2.49) than those who did not report TBI. Comparison of the log-likelihood

ratios for the two models presented in Table 2 with and without the three interactions between TBI and sex, TBI and age, and TBI, sex and age, entered separately, and combined, did not show discernible improvement ($P > 0.05$) with one exception. The interaction between TBI and age was statistically significant ($F (3,3860) = 2.99$, $P = 0.03$) against the main effects only model predicting self-reported ADHD, $F (11,3852) = 6.55$, $P < 0.001$. The distinguishing feature of the 2-way interaction involves differing associations between younger and older adults. The odds ratios of self reported ADHD were 3.64 times higher (95% CI: 1.38, 9.62) and 5.81 (95% CI: 2.06, 16.36) among individuals with TBI than those with no history of TBI, among 18 to 29 year olds and individuals over 50 years of age, respectively, they did not differ significantly among 30 to 39 year olds (AOR=.15; 95% CI: .02, 1.40) and 40 to 49 year olds (AOR=2.42; 95% CI: .55, 10.68). Thus, although the TBI-ADHD/ASRS association presented in Table 2 shows a roughly similar association for all categories of sex, age and sex by age groupings, the history of lifetime TBI-ADHD association does differ for age groupings.

DISCUSSION

Our results show that adults sustaining a lifetime TBI had greater odds of lifetime ADHD diagnosis and screening positive for current ADHD. These findings corroborate pediatric studies that link the two conditions, and suggest that this association is also evident in adult populations, and among adults with current ADHD symptoms, as well (Adeyemo et al., 2014; Eme, 2012). However, the association between lifetime TBI and lifetime ADHD diagnosis appeared restricted to young adults aged 18 to 29. This interactive relationship might be related to greater overlap in the mechanism of TBI and ADHD during early adulthood than late adulthood (Bonfield et al., 2013; Coronado et al., 2011; Centre for Disease Control and Prevention, 2010; Faul et al., 2010; Gilchrist, 2011; Ilie et al., 2015). Indeed, in the past 15

years there has been a rise in TBI due to sports injuries among youth, but also ADHD (Bonfiled et al., 2013; Faul et al., 2010). According to a recent retrospective study based on hospital records, children who experienced concussions as a result of sports participation were more likely to be moderately disabled post injury when they also had ADHD compared to children without ADHD, even after controlling for age and sex [Bonfield et al., 2013].

The observed prevalence of ASRS-ADHD self-reported symptoms is consistent with the average prevalence of 3.4% (range 1.2-7.3%) found in a review of other countries using similar epidemiological sampling methodology (Fayyad et al., 2007). Kessler et al. (2006), using the same screening instrument, found 4.4% screened positively for ADHD, but their sample was limited to American adults 18-44 years of age. Our sample had an age range of 18-97, and evidence indicates less self-reported symptomatology with older cohorts. Our lifetime TBI prevalence among adults of 17.1% is comparable to adult TBI estimates based on hospitalization records in the US (Faul et al., 2010) and it is closely related to the lifetime TBI estimate (20.2%) of a population-based sample of adolescents in Ontario (Ilie et al., 2013). The 3.1% difference between the adult and adolescents prevalence rates may reflect increases in sports related TBI among adolescents in recent years reported by the Center for Disease Control and Prevention (Gilchrist, 2011).

Although our data do not allow us to comment on temporal ordering of ADHD and TBI, the largely paediatric literature on this association suggests that the association between ADHD and TBI is not coincidental (Adeyemo et al., 2014; Bonfield et al., 2013; Gerring et al., 1998; Hughes et al., 2013; Keenan et al., 2008; Kessler et al., 2006; Ornstein et al., 2013; Vingilis et al., 2015; Weyandt & DuPaul, 2006; Zwi & Clamp, 2008). TBI may lead to psycho-neurological changes that in turn facilitate ADHD, or ADHD may increase the

probability that an acute event (fall, crash, accident) will occur that will result in a TBI. Impulsive, hyperactive and inattentive tendencies can reflect both ADHD and TBI, and may be the reason why males have been found to experience both conditions more than females (Adeyemo et al., 2014; Bonfield et al., 2013; Kessler et al., 2006; Ilie et al., 2013; 2014a,b; Okie, 2006; Slomine et al., 2005; Thornhill et al., 2000; Weyandt & DuPaul, 2006; Zwi & Clamp, 2008). We observed that the odds of ADHD (either self-reported lifetime or current symptomatology) were greater among adults with lifetime brain injury even when we held constant values of sex, age, and education. Therefore, it may be useful to assess TBI history during screening and assessment of ADHD in the adult population.

While the causal links between TBI and ADHD are not fully understood it seems likely that adults with ADHD are more likely to engage in risky behaviours that could exacerbate any problems they may be experiencing post TBI and that may further impair any treatment regimen (Gerring et el., 1998; Ornstein et al., 2013). Given that post TBI conditions may take time to develop, adults with ADHD may not recall a TBI event or its details that preceded their ADHD symptoms and not link the two during clinical interviews and thus clinically important associations may go undiagnosed.

Although of substantial interest, our results are subject to important limitations. First, our results are based on self-report and thus subject to measurement bias that may affect our prevalence estimates. Although there is little research on the validity of self-reported TBI, the literature on the validity of self-reported injuries indicates that they are still regarded as the best available means to estimate such individual behaviours in the population (Hu et al., 2011; Ialomiteanu et al.; 2011; 2013; Tait et al., 2010). Also, our response rate (51%), while considered very good for a survey of this nature, represents a risk for nonresponse bias

(Ialomiteanu et al.; 2011; 2013). A final limitation of our study is that the cross-sectional nature of the research does not allow determination of causation. Longitudinal studies are needed to determine what causal pathways may connect ADHD and TBI.

Despite these limitations, this study provides important new information. First, the association between these two conditions occurs for adults as well as adolescents and is a matter for clinical attention. Second, the two measures of ADHD – screener-based and summary item based – provided similar results. Third, with one exception, the TBI-ADHD association appears robust, occurring roughly similarly among all categories of sex and education. One exception was found in the association between lifetime TBI and lifetime ADHD diagnosis, which was restricted to the younger adult group (18 to 29 years) and may be related to greater overlap in the mechanism of TBI and ADHD during early adulthood (Bonfield et al., 2013). Future research should assess if additional harm is associated with co-occurring TBI-ADHD compared to a single condition. , and whether age and sex moderate the association of the combination of TBI andADHD with health outcomes. Longitudinal studies, and studies collecting data on the timing of onset of these two conditions are needed to determine causal pathways. Finally, person-centered investigations such as latent class analysis could identify clinically meaningful subtypes of individuals with distinct patterns of symptomology that may have implications for treatment and its delivery.

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