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Traumatic brain injury and hazardous/harmful drinking: Concurrent and single associations with poor mental health and roadway aggression

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ABSTRACT

This study describes the association among lifetime traumatic brain injury (TBI) and past year hazardous/harmful drinking, as well as their unique and synergistic effects, on mental health problems and roadway aggression among Canadian adults. A cross-sectional sample of 6074 Ontario adults aged 18 years or older were surveyed between 2011 and 2013. TBI was defined as trauma to the head resulting in loss of consciousness or overnight hospitalization. Past year hazardous/harmful drinking was assessed using the Alcohol Use Disorders Identification Test. An estimated 13.1% (95%CI:12.0,14.2) adults reported a prior TBI (no hazardous/harmful drinking), 2.7% (95%CI:2.2,3.3) reported a prior TBI while concurrently screening positive for past year hazardous/harmful drinking and 9.8% (95%CI:8.9,10.9) screened positive for hazardous/harmful drinking (no TBI). Men had significantly higher odds of exhibiting all three conditions compared to women, especially for the concurrent class. Younger adults had significantly greater odds of hazardous/harmful drinking, or the concurrent class compared to adults 55 years and older. Adults in any of the three conditions had greater odds for mental health problems and roadway aggression. Concordance of both conditions corresponded to a greater than additive effect and greater odds of mild roadway aggression, than either condition alone. Results show that singly and jointly, these conditions are associated with adverse health and behavioral impediments.

1. Introduction

The co-occurrence and association between hazardous drinking and traumatic brain injury (TBI) is quite common though research efforts in the past 20 years have been modest at trying to better understand the adverse health implications associated with it (Corrigan and Lamb-Hart, 2004). As many as two thirds of adults with TBI are identified as hazardous drinkers and as many as half report having been injured while they were intoxicated, and continue to drink heavily after their injury (Corrigan, 1995; Corrigan et al., 1999).

There is growing recognition that TBI produce greater population harm than many other chronic conditions (Centers for Disease Control and Prevention, 2015; World Health Organization, 2004). While in the United States, every year approximately 1.7 million TBIs are counted using hospitalization, emergency visits and death records, in Canada the incidence rate (using the same count criteria) is approximately 500,000, and incidence rates are reported to be on the rise in both countries (Brain Injury Association of Canada, 2014; Faul et al., 2010). These high incidences, however are likely to be underestimates as many TBIs (defined in these reports as external physical force to the head or other mechanisms of displacement of the brain within the skull) go unreported (Brain Injury Association of Canada, 2014; Faul et al., 2010; Veliz et al., 2017). Reports assessing incidence of TBI in the population indicate that older adults, teens and males are most vulnerable to sustain a TBI (Faul et al., 2010; Ilie et al., 2013; Veliz et al., 2017).

Prevalence of a lifetime TBI among adolescents has been estimated at 1 in 5, and among adults at 1 in 6 in North America (Faul et al., 2010; Veliz et al., 2017). TBIs have been identified as a leading cause of disability and death among adults and children (Ilie et al., 2013; Lu et al., 2005; Tagliaferri et al., 2006). There is a wide variation in the outcomes of TBI based on severity between individuals (Gamboa et al., 2006). TBI can cause a wide range of functional changes including

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thinking, sensation, language, and emotions and may affect many aspects of an individual's life (Dillahunt-Aspillaga et al., 2015). Even mild TBIs have substantial effects on a person's life. The deficits associated with a mild TBI usually subside quickly, but about 15% of patients with mild TBIs experience symptoms for longer than a year (Ilie et al., 2017; Taylor et al., 2017). Moreover, deficits may only present when the patient attempts to resume the full demands characteristic of their life preinjury (Shames et al., 2007).

Economic cost studies reveal that total annual direct and indirect costs associated with TBI were estimated at $77 billion in the United States, and over €100 billion in Europe (Finkelstein et al., 2006; Gustavsson et al., 2011). Among all conditions requiring rehabilitation, back pain and arthritis (osteoarthritis and rheumatoid arthritis) are the most common and costly conditions, followed by stroke and TBI (Ma et al., 2014). While TBIs are less common than arthritis, back pain and stroke, they carry enormous per capita direct and indirect costs, mostly due to the young age of those affected and the severe disability that it may cause (Ma et al., 2014). Residual effects following TBI can include cognitive deficits and psychiatric and mental health impediments, all of which shape personal relationships as well as health, social, and vocational functioning (Dean and Steer, 2013; Wehman et al., 2005; Yasuda et al., 2001)).

Hazardous/harmful drinking remains one of the leading causes of disease and disability in the Americas placing burdens on the medical care system (Lim et al., 2012). Indeed, hazardous/harmful drinking is associated with the development of many chronic diseases, mental health impediments, acute injuries, physical trauma, violence, and drug use (Anderson et al., 2009; Babor et al., 2010; Ilie et al., 2013, 2014a, b, 2015a, b, c, 2016; Norström, 2007; Mann et al., 2001, 2003, 2005; Rehm et al., 2008; Skög, 2001; 2003; Wickens et al., 2013a, b). Alcohol is consumed by an estimated 85% of Ontario adults, and in Canada, alcohol consumption has increased by a third between 1996 and 2010 (Ialomiteanu et al., 2011; Statistics Canada, 2011). Some 20% of Canadians who consume alcohol exceed low-risk drinking guidelines (Canadian Public Health Association, 2011; Ialomiteanu et al., 2009), and in 2013, some 6.8% of Ontarian adults engage in risky single occasion drinking—consuming five or more drinks on a single occasion – at least weekly (Ialomiteanu et al., 2014).

Hazardous/harmful drinking has been found to be both a recognized contributor and consequence of TBI in both adolescents and adults (Ashman et al., 2004; Ponsford et al., 2007). Moreover, between one third to one half of adolescents and adults who were hospitalized due to a TBI were intoxicated at the time of injury, and among those who required inpatient rehabilitation post-TBI, over 60% also had a history of alcohol or other drug misuse (Corrigan, 1995; ; Corrigan et al., 1998, 1999; Gordon et al., 2006; Parry-Jones et al., 2006; Savaola et al., 2005; Tagliaferri et al., 2006). Further, it has been shown that the likelihood of incurring a TBI as a result of excessive alcohol consumption rises significantly as blood alcohol content increases (Bjork and Grant, 2009; Corrigan, 1995; Graham and Cardon, 2008; Parry-Jones et al., 2006; Taylor et al., 2003). Alcohol is a known source of complications post-injury among adults, and it is known to be responsible for the lack of relief or lessening of symptoms associated with the injury, otherwise observed, over time (Bombardier et al., 2003; Corrigan, 1995; Ponsford et al., 2007). Researchers and health professionals report several cognitive and socio-emotional impairments caused by TBI which present unique problems when linking it with hazardous/harmful drinking (Center for Substance Abuse Treatment, 1998; Langley, 1991; Corrigan et al., 1999; Ilie et al., 2016).

TBI severity is associated with alcohol consumption post-injury (Corrigan et al., 1999). Age at TBI onset and frequency of TBI incidents may also alter the development or expression of substance use disorders among individuals with a prior TBI. Most studies relating TBI with alcohol consumption examine the presence or absence of TBI in one's lifetime and report that among individuals currently enrolled in substance abuse treatment who reported a single TBI episode, the average age of TBI onset is 26.9 (SD = 11.6) (Sacks et al., 2009). However, individuals with *multiple TBIs* have an average age of onset of 14.5 (SD = 8.9), with more initial injuries occurring up to and/or during early adolescence. This is not surprising as more adolescents ages 10–19 die due to head injuries than from all other causes of death combined (Center for Disease Control and Prevention, 2009).

Studies suggest that the prevalence of excessive or dependent alcohol use following TBI range from 7% to 26% and is lower than pre-TBI prevalence rates (Bombardier et al., 2003; Drubach et al., 1993). Though drinking tends to initially recede in the acute phase following TBI, increases are observed in the first and second years postinjury (Bombardier, 2011; Bombardier et al., 2003; Drubach et al., 1993; Ponsford et al., 2007). Subsequent alcohol misuse among individuals with a prior TBI is more prevalent among males, those of younger age, those who consume alcohol pre-TBI, individuals who have developed depression post-TBI, and those rating their mental health as fair to moderate (Horner et al., 2005; Kreutzer et al., 1991). Past year hazardous/harmful drinking is not uncommon among youth with a prior TBI (Ilie et al., 2016). Mounting evidence indicates that individuals with a history of alcohol use pre-TBI have a more complicated course of recovery from the TBI and, in general, poor rehabilitation and social outcomes (Parry-Jones et al., 2006; Topolovec-Vranic et al., 2014).

In view of the adverse aftermath of concurrent TBI and hazardous/harmful drinking, it seems likely that their joint presence in an individual's health profile may produce synergistic adverse health consequences beyond those that might be otherwise associated with having either singly. Stated differently, the joint effects of TBI with hazardous/harmful drinking may be additive. Indeed, in a recent study of youth, we found that when a lifetime TBI and past year hazardous/harmful drinking co-occur, their associations with adverse mental health (anxiety, depression, ADHD, suicide) and conduct behaviors (bullying, violence, possession and/or use of a weapon while at school) were synergistic (Ilie et al., 2016). To our knowledge, no similar research on the concurrence of TBI and hazardous/harmful drinking and their health functioning has been conducted with adults. To this end, we investigate the typological structure of TBI and hazardous/harmful drinking, both uniquely and jointly, with cognitive, emotional, and behavioral indicators of poor mental health in the Ontario adult population.

2. Methods

Our estimation data are based on a subsample of 6,053 adults interviewed for the 2011 (n = 1999), 2012 (n = 2015) and 2013 (n = 2060) calendar-year cycles of the Centre for Addiction and Mental Health's *CAMH Monitor*, a rolling random digit dialing telephone survey of noninstitutionalized Ontario adults aged 18 or older, who were randomly designated to answer the TBI question as part of a health module. Excluded from selection were adults without telephone service, institutionalized, or unable to complete the interview in English. The multi-year sampling error calculation model employed a disproportionately stratified (6 regions by 3 cycles), two-stage (telephone number, followed by the last birthday selection method for landline household respondent) probability sample drawn quarterly by means of a list-assisted random digit dialing of listed and unlisted, landline and cellular, telephone numbers. Based on AAPOR guidelines, the *CAMH Monitor*'s eligibility-adjusted unweighted response rate average 50% (51% in 2011 and 2012, 48% in 2013) (The American Association for Public Opinion Research, 2016). A metadata description of the each cycle and discussion of potential nonresponse bias is available on the *CAMH Monitor's* webpage (Ialomiteanu et al., 2014). All cycles of the *CAMH Monitor* were approved by the Research Ethics Committees of CAMH and York University.

2.1. Measures

2.1.1. Group membership

Our outcome variable was derived from the cross-classification of 2 binary measures—hazardous or harmful drinking and history of TBI. Hazardous/harmful drinking was assessed using the 10-item AUDIT screen, a well-validated (across genders and in a wide range of racial/ethnic groups) World Health Organization-sponsored instrument that measures aspects of drinking frequency, volume, excessive consumption and symptoms of abuse and dependence due to alcohol (Babor et al., 2001). An AUDIT score at or above 8 (coded 1) screens for the presence of hazardous/harmful drinking and contrasts these cases to those failing to screen positive (coded 0) (Carey, Carey and Chandra, 2003; Reinert and Allen, 2002).

Traumatic brain injury (TBI) sustained in one's lifetime was assessed by a single item 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 an injury like this?* Open-ended counts responses were binary coded to depict history of lifetime TBI (yes = 1; no = 0). This definition of TBI is used in several classification systems including the DSM-IV and has previously been used in adolescent and adult studies (Anstey et al., 2004; Tait et al., 2010).

The first set of analyses (reported in Tables 2 and 3) were based on the following 4 categories. The null baseline category comprised adults who failed to screen positive for both TBI and hazardous/harmful drinking (n = 4608). The second category comprised adults with a history of TBI, but no hazardous/harmful drinking (n = 848). Members in the third category comprised adults without a lifetime TBI but screened positive for hazardous/harmful drinking (n = 485). The fourth and final category comprised past year hazardous/harmful drinkers with co-occurring history of TBI (n = 133).

The second set of analyses (Table 4) were based on a TBI-hazardous/harmful drinking typology with the following 3 categories: (1) the null category of adults without lifetime TBI and past year hazardous/harmful drinking (n = 4608); (2) adults who reported either a history of TBI or screened positive for hazardous/harmful drinking (n = 1333); and (3) adults who reported a history of TBI and also screened positive on the AUDIT (n = 133). These analyses speak to the question of whether the presence of both TBI and hazardous/harmful drinking on individuals was greater than the impact of either by itself.

2.1.2. Indicators of poor mental health

Eleven indicators of poor mental health included cognitive-emotional and behavioral variables and are summarized in Table 1 (Able et al., 2007; Adler et al., 2006; Goldberg and Williams, 1988; Kessler et al., 2005). Six cognitive-emotional (including self-rated physical and mental health status as well as diagnostic indicators) and five behavioral (including suicide attempt and roadway aggression) indicators of poor mental health were included.

2.1.3. Covariates

Four covariables were also modeled (Table 1): sex (male versus female), age (18–33 years, 34–54 years, versus 55+ years), and prior year household income (<$30,000, $30,000-$79,999, versus $80,000+), all of which have been found to be associated with both TBI and hazardous/harmful drinking. As well to ensure that our findings were not influenced by any changes in sample attributes across years, we also held fixed survey year (2011–2013).

2.2. Statistical analysis

To accommodate the violation of independence of observations assumption incurred by our disproportionate stratification and diverse inclusion weights, we employed pseudo maximum likelihood estimation to estimate point estimates and Taylor Series Linearization (TSL) available in the Complex Sample module in SPSS V20.0 (Heeringa et al., 2017; Korn and Graubard, 1999; West, 2011, West et al., 2008). Moreover, our sample of 6074 respondents was well-distributed among the 18 strata, with subclass observations ranging from 318 to 362 across strata. Although all analyses are based on listwise exclusion of 'don't know', refusal and missing responses, only 0.43% of our analytic sample are listwise missing. The unweighted mean age of the respondents who answered the TBI questions was 47.3 years (range:18–97; SD = 17.17) and 48.2% were male.

3. Results

Beginning with our quadnomial outcome, we find an estimated 13.1% (95% CI:12.0,14.2; n = 848) of Ontario adults were classed as having had a prior TBI but failing to screen positive on the AUDIT; 9.8% (95% CI:8.9,10.9; n = 485) were classed as hazardous/harmful drinkers (screened positive on the AUDIT) but without a prior TBI; 2.7% (95% CI:2.2,3.3; n = 133) were classed as having a prior TBI and were identified as hazardous/harmful drinkers; and, 74.4% (95% CI:72.9,75.8; n = 4608) were classed as having neither a prior TBI nor a positive AUDIT. The corresponding population estimates of the 3 positive categories were 2,597,388, 1,304,309, and 705,248.

For the purpose of identifying candidate regressors, Table 2 presents a series of four simple multinomial logit models regressing TBI-drinking on demographic characteristics of the sample. Odds ratios for these marginal association were significantly higher for males than females for all contrasts between the null class and the 3 TBI-Drinking classes, F (3,6027) = 51.04, $p < 0.001$. Males had odds nearly 2 times (OR = 1.97; 95% CI:1.62,2.38), 3 times (OR = 3.28; 95% CI:2.56,4.21), and roughly 5 times (OR = 5.44; 95% CI:3.20,9.25) that of females for a prior TBI, screening positive for hazardous/harmful drinking, or both, respectively, compared to individuals not incurring either. Age was significantly associated with TBI-drinking membership, F(6,5892) = 17.77, $p < 0.001$. Relative to adults aged 55 and older, those aged 18–33 had odds nearly 4 times greater (OR = 3.91, 95% CI:2.93,5.21) to report hazardous/harmful drinking (no TBI) and odds roughly 3 times greater (OR = 3.40, 95% CI:1.98,5.85) to sustain coinciding hazardous/harmful drinking and a prior TBI than to sustain neither condition. Odds ratios contrasting TBI (no hazardous/harmful drinking) membership did not differ significantly for adults aged 18–33 versus those aged 55+. Relative to adults in this older group, those aged 34–54 faced the greatest odds of experiencing both hazardous/harmful drinking and TBI history (OR = 2.01, 95% CI:1.25,3.22), followed by hazardous/harmful drinking only (OR = 1.76, 95% CI:1.36,2.28) relative to the base category. Adults aged 34–54 faced no greater odds of a prior TBI alone relative to those aged 55+ (OR = 1.12, 95% CI:.93,1.35). Prior year household income was significantly associated with TBI-drinking membership, F(6,4582) = 3.78, $p < 0.01$. Compared to persons who declared annual incomes of $80,000+, those who declared between $30,000 and $79,999 had lower odds of being identified as hazardous/harmful drinkers (OR = 0.058, 95% CI:.044,0.76). No other income contrasts were significant. Although survey year was not significantly associate with TBI-drinking membership, F(6,6024) = 0.64, $p > 0.05$, we retained this design covariable to ensure that any covariate change is factored in the analysis.

Results we describe below are reported with covariates included except in cases where results differ when covariates are included in which case results both with and without the covariates are described. Table 3 shows the results of a series of 11 multinomial logit models regressing TBI-hazardous drinking membership on cognitive-emotional and behavioral indicators of poor mental health while holding fixed our 4 covariates. Self-rated poor mental health, psychological distress, lifetime ADHD diagnosis, past year ADHD symptoms, and suicide ideation were statistically significant cognitive-emotional predictors of

Table 1
Indicators of poor mental health and covariates included in the analysis.

Variable	Definition
Cognitive–emotional indicators	
Self-rated mental health	rating one's mental health as fair/poor versus (excellent/good)
Self-rated health	rating one's physical health as fair/poor versus (excellent/good)
Psychological distress	3+ symptoms on the 12-item version of the GHQ (Goldberg and Williams, 1988) at the time of testing versus (<3 symptoms). A cut score of 3 or more on the binary-scored GHQ-12 is considered the validated threshold identifying someone as experiencing elevated psychological distress during the past few weeks. Cronbach's reliability-coefficient (α) for these 12 items in this sample is 0.89.
ADHD diagnosis	lifetime diagnosed of ADHD versus (never diagnosed)
Current ADHD symptom	>13 points on the 30 points version of the ASRS V1 (Able et al., 2007; Adler et al., 2006; Kessler et al., 2005) at the time of testing versus (≤13 points). This is a 6-item, 5-point Likert screener which has been demonstrated superior specificity (99.5%), sensitivity (68.7%), total classification accuracy (97.9%), and kappa (0.76) (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.
Suicide ideation	seriously considered suicide in the past 12 months versus (not)
Behavioral indicators	
Attempted suicide	attempted to commit suicide in the past 12 months versus (not)
Medication to reduce anxiety or panic attacks	taken prescribed medication to reduce anxiety or panic attacks in the past 12 months versus (not)
Medication to reduce depression	taken prescribed medication to reduce depression in the past 12 months versus (not)
Mild road-related aggression	shouted, cursed, or made rude gestures at a driver or passenger in another vehicle in the past 12 months versus (not)
Severe road-related aggression	threatened or attempted to injure a driver or passenger in another vehicle, or threatened or attempted to damage another vehicle in the past 12 months versus (not)
Covariates	
Sex	Male versus (female)
Age	18–33 years; 34–54 years; (55+ years)
Household income	<$30,000, $30,000–$79,999, ($80,000+)
Year interviewed	2011, 2012, (2013)

Note: entries in parentheses are reference groups.

hazardous/harmful drinking. Taking prescribed medication for anxiety or panic attacks and mild road-related aggression were significantly significant behavioral predictors of hazardous/harmful drinking. For all but two of the mental health indicators assessed, odds ratios associated with lifetime TBI solely (without hazardous/harmful drinking), ranged from 1.39 to 4.69 and were statistically significant, compared to individuals in the null base category. When sex, age, income and survey year were held fixed, all 9 odds ratios remained significant and ranged from 1.61 to 4.40. All of the cognitive-emotional indicators of poor mental health were significantly associated with a prior TBI, without hazardous/harmful drinking, including self-rated poor health and mental health, psychological distress, suicide ideation, past year or past ADHD diagnosis, and past year ADHD symptoms. Although mild road-related aggression was not associated with prior TBI, taking prescribed medication for anxiety or for depression and severe road-related aggression were statistically significant predictors of TBI in one's lifetime.

When sex, age, income and survey year are held fixed, 7 (4 cognitive-emotional and 3 behavioral indicators of poor mental health) of the 11 odds ratios stood significant and ranged from 1.73 to 5.83 for the combined occurrence of TBI with hazardous drinking versus baseline. Five (subjective health, elevated psychological distress, having taken medication for depression, mild road-related aggression and sever road-related aggression) of these 7 odds ratios were higher for the cooccurrence of TBI and hazardous drinking, than the odds ratios observed for either condition (TBI or hazardous drinking) alone. Concurrent hazardous/harmful drinking and a prior TBI had statistically significant odds ratios associated with 8 of the 11 mental health indicators, ranging from 1.94 to 9.67.

In order to investigate the incremental contribution of experiencing co-occurring TBI and hazardous/harmful drinking compared to either condition by itself (referent), Table 4 presents 11 multinomial logit model regressing the 3 category TBI with hazardous drinking on each of the mental health indicators. Comparisons between the two groups failed to reveal statistical significance on all but one of the 11 mental health indicators. Members of the co-occurring group had significantly higher adjusted odds of reporting mild roadway aggression compared to those encountering only one of these conditions. The analysis also contrasted respondents reporting either hazardous/harmful drinking or a prior TBI (referent) with those who reported neither condition. Results showed that the group experiencing neither condition had lower odds than the group experiencing either hazardous/harmful drinking patterns or TBI history to experience any of the 11 indicators of cognitive-emotional or behavioral indicators of poor mental health, with the exception of attempted suicide for which no significant difference was evident.

4. Discussion

Almost one in 8 adults had a prior TBI but was not identified as a hazardous/harmful drinker (13.1%; 95% CI:12.0,14.2), one in 10 was identified as a hazardous/harmful drinker but did not report a prior TBI (9.8%; 95% CI:12.0,14.2), and one in 37 had a prior TBI and was identified as a hazardous/harmful drinker (2.7%; 95% CI:2.2,3.3). The TBI lifetime prevalence estimate in our sample (15.8%; irrespective of hazardous/harmful drinking) compares to adult TBI prevalence estimates based on hospitalized records alone in the US. Our estimate is 10.1 percentage points higher than a 5.7% lifetime TBI prevalence found among 7,485 Australian adults in 2004 (Butterworth et al., 2004). However, the Australian sample was evaluated against a minimum 15-min loss of consciousness, which represents more severe cases of TBI than those detected by our minimum 5-min loss of consciousness. The estimated prevalence of hazardous/harmful drinking in these data, regardless of TBI history is 12.5%, which is similar to other North American population estimates based on the AUDIT (World Health Organization, 2014). Corroborating the existing literature, membership in both classifications, compared to baseline, was more common among men than women (Bombardier and Turner, 2009; Brown et al., 2010; Corrigan and Lamb-Hart, 2004; Faul et al., 2010).

To our knowledge, no previous studies of adults appraised the typology we have reported here. Thus, there is no available comparison for our estimate of a prior TBI with past year problem drinking among adults. However, Bombardier (2011) found that as many as 67% of persons with TBI have a prior alcohol abuse or risky drinking and that between one third and one half of persons with TBI acquired the injury

Table 2
Descriptive analyses predicting membership classification: prior TBI only (no current hazardous/harmful drinking); hazardous/harmful drinking only (no prior TBI); prior TBI and hazardous/harmful drinking; and baseline (no TBI or hazardous/harmful drinking) by demographics among adults aged 18+, Ontario, Canada, 2011–2013, n = 6074.

	Base category % (95% CI) Odds ratio (95% CI) n = 4608	TBI (no hazardous/harmful drinking) % (95% CI) Odds ratio (95% CI) n = 848	Hazardous/harmful drinking (no TBI) % (95% CI) Odds ratio (95% CI) n = 485	TBI and hazardous/harmful drinking % (95% CI) Odds ratio (95% CI) n = 133
Sex	F (3, 6027) = 51.04**			
Male	41.9% (40.1, 43.8)	58.7% (54.3, 62.9)	70.3% (65.2, 75.0)	79.7% (69.9, 86.9)
	1.0 (Reference)	1.97 (1.62, 2.38)**	3.28 (2.56, 4.21)**	5.44 (3.20, 9.25)**
	n = 1622	n = 419	n = 308	n = 105
Female (Ref.)	58.1% (56.2, 59.9)	41.3% (37.1, 45.7)	29.7% (25.0, 34.8)	20.3% (13.1, 30.1)
	n = 2986	n = 393	n = 174	n = 28
Age category	F (6, 5892) = 17.77**			
18–33	23.1 (21.3, 25.1)	21.1 (16.9, 26.1)	45.8 (40.1, 51.6)	40.3 (29.9, 51.7)
	1.0 (Reference)	0.94 (0.69, 1.28)	3.91 (2.93, 5.21)**	3.40 (1.98, 5.85)**
	n = 521	n = 78	n = 136	n = 33
34–54	39.3 (37.5, 41.1)	42.6 (38.2, 47.0)	35.2 (30.2, 40.4)	40.4 (30.8, 50.9)
	1.0 (Reference)	1.12 (0.93, 1.35)	1.76 (1.36, 2.28)**	2.01 (1.25, 3.22)*
	n = 1569	n = 314	n = 188	n = 57
55+ (Ref.)	37.6 (35.9, 39.2)	36.3 (32.5, 40.3)	19.0 (15.8, 22.7)	19.2 (13.4, 26.8)
	n = 2399	n = 413	n = 153	n = 42
Household income	F (6, 4582) = 3.78*			
<$30,000	10.2% (9.1, 11.5)	12.1% (9.7, 15.1)	8.3% (5.6, 12.2)	6.2% (3.1, 12.0)
	1.0 (Reference)	1.25 (0.92, 1.70)	0.66 (0.42, 1.04)	0.53 (0.24, 1.23)
	n = 497	n = 114	n = 43	n = 15
$30,000–$79,000	37.3% (35.3, 39.3)	38.1% (33.7, 42.6)	26.6% (2.0, 31.8)	33.5% (24.0, 44.6)
	1.0 (Reference)	1.08 (0.86, 1.34)	0.58 (0.44, 0.76)	0.78 (0.48, 1.28)
	n = 1414	n = 274	n = 141	n = 44
$80,000+ (Ref.)	52.5% (50.4, 54.6)	49.8% (45.1, 54.5)	65.0% (59.3, 70.3)	60.3% (49.2, 70.4)
	n = 1499	n = 265	n = 228	n = 59
Year interviewed	F (6, 6024) = 0.641			
2011	32.5% (30.9, 34.3)	32.5% (28.5, 36.7)	31.2% (26.5, 36.5)	39.8% (29.7, 50.9)
	1.0 (Reference)	1.08 (0.86, 1.36)	0.95 (0.71, 1.27)	1.38 (0.81, 2.34)
	n = 1502	n = 274	n = 169	n = 44
2012	32.7% (23.0, 25.7)	35.3% (31.1, 39.8)	33.6% (28.6, 39.0)	29.3% (21.1, 39.2)
	1.0 (Reference)	1.17 (0.92, 1.48)	1.02 (0.76, 1.36)	1.01 (0.60, 1.70)
	n = 1529	n = 263	n = 164	n = 42
2013 (Ref.)	34.8% (33.0, 36.6)	32.3% (28.3, 36.3)	35.2% (29.8, 40.9)	30.8% (22.1, 41.2)
	n = 1577	n = 275	n = 149	n = 47

Note: Ref. = reference category.
* $p < 0.01$.
** $p < 0.001$.

while they were intoxicated. Other studies examining TBI among adults currently receiving substance abuse treatment have found rates between 38% and 63%, higher rates being found by operational definitions of TBI that are similar to the one we adopted (i.e., a minimum 5-min loss of consciousness) (Gordon et al., 2002; Hillborn and Holm, 1986). A previous work using our TBI-drinking typology was conducted on a population sample of Ontario youth aged 13–20 years (Ilie et al., 2016). Prevalence estimates for hazardous/harmful drinking, a prior TBI, and their joint prevalence among adolescents were 3.9, 2.7, and 3.6 percentage points higher than the estimated prevalence among adults in the current study. To our knowledge these are the first two studies comparing the individual and combined associations of these conditions with adverse health and behavioral correlates among adults and adolescents, in the same population. Our results show adolescents fare worse than adults in the prevalence of these conditions alone, and in combination, and also with respect to their associations on adverse health and behavioral correlates (Ilie et al., 2016). Previous studies on brain structure and function that have shown how the co-occurrence of hazardous drinking with TBI has additive effects on brain impairment than either one condition alone (Zasler et al., 2013). Whether hazardous drinking contributed to the cause of injury, or it emerged after the injury it places the person at risk for poor health and behavioral outcomes and medical complications (Groves et al., 2009; Ilie et al., 2016). Taken together these results point to the need to address the increased medical and health risks that the co-occurrence of TBI with hazardous drinking pose in rehabilitation but also prevention.

Our results showed no significant incremental impact of their joint presence on adverse mental health measures compared to either condition alone. These findings differ from similar comparisons conducted among Ontario adolescents (13–20 year-olds), which showed an incremental impact of the concurrent prior TBI and hazardous/harmful drinking on 6 mental health-related outcomes (elevated psychological distress, medication for anxiety, medication for depression, suicide ideation, suicide attempt, poor mental health in general) (Ilie et al., 2016). This difference and the higher prevalence of hazardous/harmful drinking and TBI among the adolescent sample may be explained by differences in brain development stages. As noted previously, the brain is still developing during adolescence and may be more vulnerable to co-occurring harms (TBI and hazardous/harmful drinking) than after development has ceased. To our knowledge this is the first investigation to suggest developmental differences in the cumulative association of co-occurring TBI and hazardous/harmful drinking between adolescents and adults. It is also of relevance to mention that an alternative explanation to the failure to detect many synergistic effects in the current adult sample (relative to the previously surveilled adolescent sample, Ilie et al., 2016) could be the smaller sample size of the jointly affected group in the current sample (n = 133). Future studies should attempt to replicate the current results using a larger sample.

Among the behavioral indicators, the link between the concurrence of TBI and hazardous/harmful drinking and roadway aggression provided evidence of an additive effect, with individuals in the combined classification showing statistically significant higher risk for mild, but

Table 3
Multinomial Logistic Regression analyses predicting membership classifications: prior TBI no hazardous/harmful drinking; hazardous/harmful drinking no prior TBI; prior TBI and hazardous/harmful drinking; and base category (no TBI or hazardous/harmful drinking) by mental health factors among adults aged 18+, Ontario, Canada, 2011–2013, n = 6074.

	Prior TBI (n = 848) vs. base category (n = 4608) OR (95% CI) AOR (95% CI)	Hazardous/harmful drinking (n = 485) vs. base category (n = 4608) OR (95% CI) AOR (95% CI)	Prior TBI and hazardous/harmful drinking (n = 133) vs. base category (n = 4608) OR (95% CI) AOR (95% CI)
Cognitive–emotional indicators of poor mental health			
Subjective mental health (Reporting fair/poor mental health in general vs. excellent/ good mental health)			
F (3, 6008) = 7.02***	1.82 (1.30, 2.54)***	1.98 (1.24, 3.16)**	2.07 (1.13, 3.78)*
F (15, 4524) = 14.42***	1.64 (1.15, 2.33)**	2.36 (1.46, 3.80)***	2.16 (1.04, 4.48)*
Subjective health (Reporting fair/poor health in general vs. excellent/ good heath)			
F (3, 6013) = 12.64***	1.86 (1.45, 2.37)***	0.69 (0.47, 1.01)	2.26 (1.31, 3.89)**
F (15, 4526) = 15.21***	1.85 (1.40, 2.44)***	0.93 (0.60, 1.45)	2.25 (1.27, 4.00)**
Elevated psychological distress			
F (3, 6027) = 9.83***	1.87 (1.42, 2.46)***	1.57 (1.13, 2.18)**	2.81 (1.61, 4.92)***
F (15, 4535) = 14.81***	1.78 (1.34, 2.36)***	1.61 (1.12, 2.29)**	2.35 (1.32, 4.16)**
ADHD diagnosis			
F (3, 6017) = 8.43***	1.39 (1.30, 4.37)**	3.39 (1.78, 6.46)***	6.12 (2.34, 16.00)***
F (15, 4535) = 14.44***	2.03 (1.02, 4.05)*	2.34 (1.07, 5.15)*	3.06 (0.90, 10.37)
Current ADHD symptoms			
F (3, 5612) = 19.49***	1.77 (1.44, 2.19)***	2.09 (1.63, 2.68)***	1.94 (1.21, 3.09)**
F (15, 4212) = 14.42***	1.88 (1.48, 2.37)***	1.93 (1.45, 2.56)***	1.73 (1.02, 2.95)*
Suicide ideation			
F (3, 4033) = 4.46**	3.34 (1.49, 7.48)**	3.51 (1.48, 8.32)**	2.22 (0.75, 6.64)
F (15, 3040) = 10.40***	2.89 (1.19, 7.05)*	3.98 (1.52, 10.43)**	2.27 (0.66, 7.82)
Behavioral indicators of poor mental health			
Attempted suicide			
F (3, 4032) = 0.28	0.74 (0.14, 3.95)	0.50 (0.06, 4.12)	1.64 (0.20, 13.74)
F (15, 3039) = 9.88***	0.48 (0.05, 4.24)	0.44 (0.04, 4.91)	1.32 (0.14, 12.28)
Taken medication for anxiety or panic attacks			
F (3, 6013) = 5.12**	1.60 (1.20, 2.13)**	1.53 (1.04, 2.25)*	1.95 (0.99, 3.85)
F (15, 4527) = 14.47***	1.61 (1.16, 2.22)**	1.64 (1.04, 2.58)*	1.78 (0.87, 3.62)
Taken medication for depression			
F (3, 6009) = 7.51***	1.76 (1.32, 2.34)***	1.43 (0.95, 2.14)	2.67 (1.40, 5.06)**
F (15, 4524) = 14.86***	1.80 (1.31, 2.49)***	1.61 (0.99, 2.60)	2.96 (1.50, 5.83)**
Mild road-related aggression			
F (3, 5764) = 14.94***	1.21 (1.00, 1.47)	1.86 (1.46, 2.37)***	2.82 (1.81, 4.40)***
F (15, 4375) = 14.64***	1.16 (0.93, 1.44)	1.35 (1.03, 1.77)*	2.29 (1.44, 3.65)**
Severe road-related aggression			
F (3, 5744) = 7.33***	4.69 (2.11, 10.42)***	2.84 (1.03, 7.86)*	9.67 (2.78, 33.70)***
F (15, 4363) = 14.96***	4.40 (1.89, 10.24)***	2.16 (0.77, 6.03)	5.83 (1.57, 21.69)**

Notes: F – design adjusted Wald F tests; odds ratios (OR) and Adjusted Odds Ratios (AOR) were calculated using logistic regression. AORs were evaluated while holding fixed values of sex, age, income, and interview year;

* $p < 0.05$.

** $p < 0.01$.

*** $p < 0.001$.

not severe, forms of road-related aggression, than either condition (TBI or hazardous drinker) alone. These results are similar to those from the adolescent study, which found that the association between the presence of both conditions (TBI and hazardous drinking) and conduct behaviors (although not including driving behaviors) to be statistically significantly stronger than the associations with either condition alone (Ilie et al., 2016). This finding suggests that it may be important to give special attention to possible synergistic associations between TBI and hazardous/harmful drinking and driving behaviors specifically. While the presence of statistically significantly higher odds of poor mental health indicators for the combined as well as individual categories (TBI and/or hazardous drinking), suggests that rehabilitation and prevention efforts could be done independently or combined, the presence of statistically significant higher odds for mild roadway aggression (one of the 11 outcomes we evaluated) suggests that for this particular outcome, combined rehabilitation and prevention efforts may be warranted.

The results we report herein must be judged in light of their potential shortcomings. First, our survey population excluded the phoneless, those institutionalized or hospitalized and non-English speakers. Second, our results are based on self-reports that are subject to sources of error that may bias our prevalence estimates, although our comparison between first responders and converted refusers showed no evidence of response bias (Ialomiteanu et al., 2014). It should be self-evident however that the collection of person reported outcomes such subjective measure or even more objective measures known only to the respondent can only be collected through self-report methods. We contend that the self-reports we obtained from respondents are reasonably trustworthy. Indeed, Groves et al. (2009:196) describe earlier work (Groves et al., 2000) showing that mental health surveys produce lower nonresponse bias than do election, current events or welfare reform surveys (Groves et al., 2000, 2009). Furthermore, our TBI definition excluded milder forms of TBI, such as injuries that resulted from a hit to the head accompanied by less than 5 min LOC or the presence of an overnight hospitalization due to symptoms associated with it (e.g., the presence of symptoms that emerged after the TBI such as feeling nauseated, problems concentrating, fatigue and blurred vision). A significant body of research shows that when samples include milder forms of TBI as many as 40%–66% of individuals also report having had a prior problem drinking or use of illegal drugs (Corrigan et al., 1999).

Table 4
Multinomial Logistic Regression analyses predicting membership classifications by prior TBI and hazardous/harmful drinking: either prior TBI or hazardous/harmful drinking, separately; no prior TBI or hazardous/harmful drinking; co-occurring prior TBI with current hazardous/harmful drinking for mental health and roadway aggression among adults aged 18 +, Ontario, Canada, 2011–2013, n = 6074.

	No prior TBI or hazardous/harmful drinking (n = 4608) vs. prior TBI or hazardous/harmful drinking (n = 1333) OR (95% CI) AOR (95% CI)	Prior TBI with hazardous/harmful drinking (n = 133) vs. prior TBI or hazardous/harmful drinking (n = 1333) OR (95% CI) AOR (95% CI)
Cognitive–emotional indicators of poor mental health		
Subjective mental health (Reporting fair/ poor mental health in general vs. excellent/ good mental health)		
F (2, 6009) = 10.28***	0.53 (0.39,0.72)***	1.10 (0.58,2.07)
F (10,4529) = 16.38***	0.51 (0.37,0.71)***	1.08 (0.51, 2.30)
Subjective health (Reporting fair/ poor health in general vs. excellent/ good heath)		
F (2, 6015) = 6.81***	0.76 (0.61,0.94)***	1.70 (0.97,3.00)
F (10,4531) = 16.21***	0.67 (0.52,0.87)***	1.55 (0.87, 2.77)
Elevated psychological distress		
F (2,6028) = 9.83***	0.63 (0.50,0.78)***	1.67 (0.98, 2.86)
F (10,4540) = 16.72***	0.59 (0.50,0.74)***	1.38 (0.77, 2.47)
ADHD diagnosis		
F (2,6008) = 12.22***	0.336 (0.22,.59)***	2.17 (0.82,5.76)
F (10,4529) = 16.21***	0.46 (0.25, 0.83)***	1.39 (0.43, 4.50)
Current ADHD symptoms		
F (2,5613) = 28.96***	0.53 (0.44,.063)***	1.02 (0.63,1.65)
F (10,4217) = 17.29***	0.53 (0.43,0.64)***	0.91 (0.53,1.56)
Suicide ideation		
F (2,4034) = 6.67**	0.29 (0.15,0.57)***	0.65 (0.21,2.00)
F (10,3045) = 11.92***	0.29 (0.14,0.59)***	0.63 (0.19, 2.05)
Behavioral indicators of poor mental health		
Attempted suicide		
F (2,4033) = 0.28	0.64 (0.15,2.62)	0.39 (0.04,3.88)
F (10,3044) = 10.86***	2.22 (0.37, 13.39)	2.73 (0.24, 30.62)
Taken medication for anxiety or panic attacks		
F (2,6015) = 7.40**	0.64 (0.50,0.82)***	1.25 (0.62,2.50)
F (10,4532) = 16.34***	0.61 (0.45,0.82)***	1.08 (0.54, 2.19)
Taken medication for depression		
F (2,6010) = 10.12***	0.62 (0.48,0.80)***	1.65 (0.85,3.20)
F (10,4529) = 16.53***	0.58 (0.43,0.78)***	1.72 (0.89, 3.37)
Mild road-related aggression		
F (2,5765) = 19.34***	0.69 (0.58,0.81)***	1.94 (1.22,3.07)***
F (10,4380) = 16.09***	0.82 (0.68,0.98)***	1.87 (1.16, 3.03)***
Severe road-related aggression		
F (2,5745) = 10.40***	0.26 (0.13,0.53)***	2.49 (0.71,8.71)
F (10,4368) = 16.55***	0.31 (0.14,0.65)***	1.83 (0.49,6.86)

Notes: F – design adjusted Wald F tests; odds ratios (OR) and Adjusted Odds Ratios (AOR) were calculated using logistic regression. AORs were evaluated while holding fixed values of sex, age, income, and interview year; *$p < 0.05$;
** $p < 0.01$;
*** $p < 0.001$.

Lastly, we note that some of the outcomes we used were single item indicators which could be subject to increased error. At the same time, these measures were used as proxies for mental health and for the assessment of mental health indicators in this population since 1977 (CAMH's Monitor is one of the longest and most reputable survey of adult mental health surveillance in the world) and were shown consistently to highly correlate with other reliable and valid instruments measuring the same construct (Ialomiteanu et al., 2009, 2011, 2014).

Notwithstanding these shortcomings, our study has much strength that counterbalances many of our study's shortcomings. Firstly, our sample consists of population data which, unlike hospital records data, allow to assess subclass variability in TBI among both those receiving care and those not. Secondly, we collected measures with a known trustworthyness—with TBI derived from DSM-based criterion and hazardous/harmful drinking derived from the WHO-sponsored AUDIT. Indeed, such data have the capability to not only build epidemiological profiles regionally, but as well to further build the state of international epidemiology. Lastly, it has been documented that some 40% of 1003 peer-reviewed publications between 1995 and 2010 using data from 3 commonly used US national adolescent health surveys failed to properly estimate their complex survey (Heeringa et al., 2017). In contrast, we employed proper estimation methods to reduce the risk of faulty conclusions.

In sum, we contend that our findings make several contributions. Our results extend findings that the individual and the joint occurrence of hazardous drinking and TBI among adults are associated with significant adverse mental health and road aggression behaviors, and that the join occurrence of these conditions elevates the risk of association with some behavioral indicators of poor mental health (mild road-related aggression), above the increased risk that either condition may pose alone (Ilie et al., 2016; Tait et al., 2010; Zasler et al., 2013). This suggests that cooccurring hazardous drinking and TBI may act additively in their association with at least some behavioral poor mental health indices (e.g., road rage), perhaps though distinct neurobiological mechanisms. McAllister (2011) discusses at length our current understanding of the neuropathophysiology of TBI and how this relates to clinical presentations of behavior difficulties. For example, alterations in the brain tissue can trigger a sequence of elaborate and complex arrays of cellular and subcellular events (McAllister, 2011) and can add on an existing chronic exposure to alcohol that has already induced changes in neural circuits that control motivational processes, including arousal, reward, and stress (Gilpin and Koob, 2008). While experts state that there is a fairly predictable profile of brain regions that can be impacted by trauma to the head and related spinal events, individual differences plus the addition of neural deficits due to chronic exposure to alcohol may predispose individuals to the accumulated current mental health and behavioral problems than either condition (TBI or hazardous drinking) may elicit alone (see also, Ilie et al., 2016). Hence combining rehabilitation and prevention strategies in the case of the joint occurrence of these conditions may be necessary and should be evaluated and explored.

The harm to the individual and their family is reason enough to be concerned about the co-occurrence of these two conditions, however, there is also the concern to society in terms of harms that may be incurred in other individuals, and short and long-term costs to society associated with multiple injuries as well as jeopardized rehabilitation efforts as individuals experiencing co-occurring TBI and harmful drinking have higher rates of hazardous drinking and injury incurrence long term (Zasler et al., 2013). In conclusion, our data show that some 700,000 Ontarians are at risk for health and behavioral risks precipitated by the joint occurrence of TBI and hazardous/harmful drinking, a matter in need of attention by the medical, public policy communities as well as family/caregivers.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.psychres.2018.12.069.

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