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The effect of age on the personality and cognitive characteristics of three distinct risky driving offender groups

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A B S T R A C T

Background: We previously reported that in traffic offenders aged 19–39 years, different risky driving profiles were associated with unique personality, cognitive, and neurobiological characteristics. However, many of these characteristics evolve significantly with age. Secondary analysis on these data explored whether the characteristics associated with different risky driving profiles were influenced by driver age.
Methods: Data ($N = 138$) on three driving groups (i.e., alcohol impaired [DWI], reckless [SPEED], and impaired and reckless [MIXED]), and a low-risk control group [CTL] were stratified by age (younger: 19–28; older: 29–39). Younger and older drivers of each risky driving group were compared to their age-matched CTLs on driving simulation, personality, and cognitive control.
Results: In DWI, elevated behavioural disinhibition was observed only in older drivers. In MIXED, elevated reward sensitivity and risky driving behaviour were seen only in older drivers. In SPEED, greater risky driving and lower agreeableness personality were only seen in young drivers, while elevated sensation seeking and risk taking were observed only in older drivers.
Discussion: Unique processes predominate in distinct forms of risky driving behaviour at different developmental stages. More effective prevention strategies may require intervention tailoring based on both risky driving preference and age.

1. Introduction

Injury due to road traffic crashes represents a major burden on the health of nations (Wijnen, 2013), but in particular for individuals under the age of 30 (World Health Organization, 2015). Human factors are estimated to play a significant yet preventable role in >90% of crashes, with two forms of risky driving, recklessness (e.g., speeding) and driving while impaired by alcohol (DWI), among the most important (Dingus et al., 2016; World Health Organization, 2015). Young drivers, in whom driving inexperience, developmental processes, and heightened alcohol involvement converge, are at particular risk (Mokdad et al., 2016; Williams, 2003). Most young people experience a "maturing out" process that is reflected in reduced alcohol misuse, reckless driving behaviour, and traffic injuries (Constantinou, Panayiotou, Konstantinou, Loutsiou-Ladd, & Kapardis, 2011; Gotham, Sher, & Wood, 2003; G. Li, Braver, & Chen, 2003; Mata, Josef, & Hertwig, 2016; Miller, Spicer, & Levy, 1999). Some individuals plainly do not follow this pattern however (Gotham et al., 2003; Vingilis et al., 2013), and in the case of risky driving, this is despite repeated arrests, punishing sanctions and the danger of injury. The reasons why this occurs are uncertain - a gap that contributes to the heterogeneity problem in the risky driving population (Nochajski & Stasiewicz, 2006; Vassallo, Lahausse, & Edwards, 2016). Clarification of the factors linked to interruption of the normative transition to reduced risk taking is key to both understanding individual differences in risky driving and better design of detection and prevention protocols.

Normal maturation from adolescence to early adulthood in brain structure and associated cognitive and hormonal processes is posited to partially explain the decline in risk taking over this period (Foy, Runham, & Chapman, 2016; Jongen, Brijs, Komlos, Brijs, & Wets, 2011; Vergés et al., 2013). From this purview, two interconnected brain

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systems are particularly relevant. The reward (emotional/limbic) processing system, involving structures such as the amygdala, bed nuclei of the stria terminalis, nucleus accumbens and ventral striatum nuclei, is related to experience and sensation seeking, and can show hyperresponsivity during adolescence and early adulthood (Galvan, 2010). Personality features also reflect developmental processes related to these brain systems. The growing role of the serotonergic system with reductions in dopaminergic-driven risk taking with older age (Daw, Kakade, & Dayan, 2002) coincides with changes in measures on Big Five domains such as agreeableness and conscientiousness (Lesch et al., 1996). Lower agreeableness in particular has been associated with the propensity for risky driving in general (Dahlen, Edwards, Tubré, Zyphur, & Warren, 2012), specific styles of anger and aggressive driving (Taubman-Ben-Ari, Yehiel, Taubman, Ben-Ari, & Yehiel, 2012), and in the heightened risky driving of younger versus older drivers (Starkey & Isler, 2016; Taubman-Ben-Ari et al., 2012).

The other brain system is the cognitive control system. This system involves several brain regions, including the cerebral cortex, medial temporal and cingulate gyrus, and the ventromedial prefrontal cortex (Lovallo, 2007). This frontal system assists in goal-directed behaviour and inhibition, and typically reaches full development by the mid to late 20's (Casey, Jones, & Hare, 2008). Disruptions in frontal-limbic systems are associated with excessive risk taking in adolescents and young adults (Dahl, 2008; Gianotti et al., 2009; Mäntylä, Karlsson, & Marklund, 2009; Steinberg & Laurence, 2010), compulsive behaviours and substance abuse in adults (Bechara, Dolan, & Hindes, 2002b; Dom, Sabbe, Hulstijn, & van den Brink, 2005; Koob, 2009; Potenza, Sofuoglu, Carroll, & Rounsaville, 2011; Verdejo-Garcia & Bechara, 2009), reckless driving (Ba, Zhang, Peng, Salvendy, & Crundall, 2016; Brown et al., 2016; Cheng, Ng, & Lee, 2012; Farah, Yechiam, Bekhor, Toledo, & Polus, 2008; Foy et al., 2016; Lev, Hershkovitz, & Yechiam, 2008; O'Brien & Gormley, 2013; Ross et al., 2015; Tabibi, Borzabadi, Stavrinos, & Mashhadi, 2015), and impaired driving (Bouchard, Brown, & Nadeau, 2012; Dedovic et al., 2016; Kasar, Gleichgerrcht, Keskinkilic, Tabo, & Manes, 2010; Ouimet et al., 2007). Overall, evolution across the lifespan in these systems represents a crucial backdrop for understanding individual differences in crash risk.

As certain psychological factors (e.g., sensation seeking) appear to underlie different forms of risk taking (Iversen & Rundmo, 2002; Jonah, Thiessen, & Au-Yeung, 2001; Meil et al., 2016), the traffic safety research has frequently conflated different forms of risky driving. At the same time, specific contextual and task factors can engage cognitive control and reward systems differently, which in interaction with individual differences, could result in domain-specific risk propensities (Nicholson, Soane, Fenton-O'Creevy, & Willman, 2005). Along these lines, we (Brown et al., 2016) showed that different persistent forms of risky driving were associated with unique psychological, neurobiological and behavioural characteristics. Specifically, in male drivers aged 19–39 years, non-alcohol related reckless drivers (predominantly speeders) possessed thrill seeking, while drivers who engaged in both reckless driving and DWI showed associated with fearless behaviour. Finally, drivers who primarily engaged in persistent DWI behaviour possessed some cognitive control weakness but little sober risk taking – a finding we, as others (Van Dyke & Fillmore, 2014), have posited to reflect their selective sensitivity to alcohol's disruptive effects on self-regulatory capacities. The role of age was not addressed in these analyses, though features characterizing group differences are susceptible to maturational processes (Shulman et al., 2016).

When comparing the above risky driver groups, adjacent processes may also influence frontal-limbic systems. Alcohol misuse, as a precondition of DWI, is predicted by pre-existing anomalies in reward sensitivity and cognitive control (Squeglia et al., 2016) and also exerts acute and chronic adverse effects on them (Montgomery, Ashmore, & Jansari, 2011; Parada et al., 2012). Due to these reciprocal effects, alcohol misuse is distinct from other risky behaviours by a course that often persists into later adulthood (Wilsnack, Wilsnack, Kristjanson, Vogeltanz-Holm, & Gmel, 2009). Hence, in those who engage in frequent DWI behaviour and episodes of excessive alcohol use, self-regulatory deficits could be expected to play a large role that becomes more pronounced with increasing age and alcohol exposure.

Systematic investigations of age effects in risky driving are sparse, and what is known comes predominantly from studies using survey and psychometric methods, self-reported risky driving (e.g., (Starkey & Isler, 2016; Taubman-Ben-Ari et al., 2012), heterogeneous samples of healthy young (e.g., Dahlen & White, 2006; Schwebel, Severson, Ball, & Rizzo, 2006) and/or much older individuals (e.g., Owsley, McGwin, & McNeal, 2003; Schwebel et al., 2007). Examination of age effects using both psychometric and behavioural levels of analyses of risk taking and driving, and in established high-risk groups who are critical targets for intervention, is less common. Thus, the present study posed the following overarching question: do the behavioural risk-taking, personality, and cognitive processes associated with distinct forms of risky driving differ in younger compared to older risky drivers?

To begin to answer this question, secondary analysis was undertaken on data from Brown et al. (2016) on drivers who had been repeatedly convicted for engaging in three predominant patterns of risky driving: i) DWI alone (DWI); ii) reckless driving unrelated to alcohol and/or drugs (SPEED); and iii) both DWI and reckless driving (MIXED). This latter group reflects a prevalent risky driving profile that has been associated with unique criminological, substance misuse and problem behaviour features (Dickson, Wasarhaley, & Webster, 2013; Elonheimo et al., 2014; Jessor, 1987). Our main hypotheses were informed by the findings in the Brown et al. (2016) parent study and those in the relevant traffic safety literature, and were as follows: i) older DWI drivers show poorer cognitive control compared to their age-matched controls; ii) cognitive control deficits in DWI drivers are directly correlated to duration of alcohol misuse, which is related to age; iii) older MIXED drivers show greater reward sensitivity, sensation-seeking and risky driving propensities than their age-matched controls; iv) older MIXED drivers show poorer cognitive control than their age-matched controls; and v) younger SPEED drivers show greater risk taking propensities compared to their age-matched controls. By testing these hypotheses, as well as by conducting subsequent empirically driven exploratory analyses, we hoped to catalyze further speculation about the distinct developmental factors influencing different forms of risky driving. Pragmatically, our goal was to shed light on whether traffic safety intervention efforts could be made more specific, and hence potentially more effective, by consideration of offender age in addition to type of driving-related risk taking engaged in.

2. Methods

2.1. Site and participant recruitment

The Institutes Research Ethics Board site of study recruitment and testing site approved all study procedures (REB certificate #11/23). Inclusion criteria aimed at recruitment of three prevalent and dangerous risky driving groups: i) drivers with multiple DWI offences, but no other non-alcohol moving violations within the past 10 years (DWI); ii) drivers with multiple recent non-alcohol related reckless driving offences (i.e., predominantly excessive speed; SPEED); and iii) drivers with a combination of both DWI and reckless driving violations (MIXED). Drivers in the low-risk control group (CTL) met none of the above inclusion criteria, and had not lost more than two demerit points for any non-criminal Highway Code violations in the last two years. General study exclusion criteria were: i) health problems that precluded safe participation; ii) less than 6th grade academic achievement; and iii) used alcohol and/or drugs within 12 h of the testing session, which was corroborated by biological assessment.

Four age-matched groups of male drivers ($N = 138$; aged 19–39 years) were recruited in the parent study: three risky driving groups (DWI, $n = 36$; MIXED, $n = 27$; SPEED, $n = 28$), and a low-risk control group (CTL, $n = 47$). Recruitment relied on advertisements placed in local newspapers and on the research team's website, and $180 CDN compensation for the 8-hour protocol conducted in the parent study.

2.2. Sociodemographic characteristics, substance use, and driving history

The Addiction Severity Index (Daeppen et al., 1996) provided self-reported information on sample sociodemographic characteristics and convictions for major driving offences. The Michigan Alcoholism Screening Test (MAST) yielded an index of lifetime alcohol problem severity and consequences (Conley, 2001). Alcohol Use Disorder Identification Test (AUDIT) (Conley, 2001) assessed alcohol problem severity and consequences in the previous 12 months. The Drug Abuse Screening Test (DAST) (Skinner, 1982) yielded an index of lifetime drug misuse severity and consequences, while the Timeline Follow Back (TLFB) (Sobell, Sobell, Connors, & Agrawal, 2003) measured daily alcohol and drug intake in the past 90 days, including number of risky drinking (i.e., ≥5 standard drinks) days. Breathalyzer® detected the presence of alcohol in breath, and Drugwipe® 6S detected recent drug use in saliva, including cannabis, cocaine, benzodiazepines, amphetamines, methamphetamines, opiates. Participants were also asked about their age of licensing, and driving exposure (km/year), and frequency of DWI behaviour in the previous 12 months.

2.3. Dependent variables of interest

To avoid inflation of Type 1 error rates, the driving, personality and behavioural variables used in this study were limited to those that significantly discriminated between risky driving groups in the parent study.

2.3.1. Behavioural risk taking

Measurement of risky driving behaviour was undertaken via a portable three-screen driving simulator developed at the University of Sherbrooke. Following 10 min of practice, participants undertook a 12.5 km simulated drive with a 100-km/h highway section with 70 km/h merging ramps, and an urban section with pertinent traffic features. Measures indicating risky driving were operationalized as mean speed in highway settings, acceleration (i.e., pedal deflection ranging from 0 minimum to 1 maximum acceleration) when an adjacent vehicle merges on the highway at matched speed, and acceleration from an intersection with an adjacent vehicle when light turns from red to green. Participants were instructed to drive normally.

2.3.2. Personality characteristics

The NEO Five-Factor Inventory (NEO-FFI) (Costa & McCrae, 2001) measured the “Big Five” personality dimensions, with agreeableness retained for this analysis. The UPPS Impulsive Behaviour Scale (Whiteside & Lynam, 2001) measured four dimensions of impulsivity, with sensation seeking retained for this analysis. The Sensitivity to Punishment and Sensitivity to Reward Questionnaire (SPSRQ) is based upon Gray's model of personality (Gray, 1987; Torrubia, Ávila, Moltó, & Caseras, 2001), with sensitivity to reward retained here.

2.3.3. Behavioural tasks of reward sensitivity and cognitive control

The computerized BIOPAC™ version of the Iowa Gambling Task (IGT) (Bechara, Damasio, Tranel, & Damasio, 2005) indexes emotion-based decision-making, in which lower scores indicates a bias for smaller rewards sooner than larger ones later. Decision making under ambiguity (i.e., when outcome probabilities are unknown) was retained for this analysis. The Stoplight Task (Chein, Albert, O'Brien, Uckert, & Steinberg, 2011) is a behavioural task that is sensitive to functional reward- or thrill-seeking biases (Steinberg et al., 2008). The Connor's Continuous Performance Test (CPT-2) (Homack, 2006) (Multi-Health Systems) yields behavioural indicators of cognitive control, with greater frequency of commission errors and shorter hit reaction time (Lezak, Howieson, & Loring, 2004) indicating elevated disinhibition and impulsivity, respectively.

3. Procedures

When study candidates called, study information was provided and inclusion/exclusion determined. If they met inclusion criteria, an experimental session was scheduled starting at 8:30, and instructions for pre-session drinking, drug and cigarette use, and food and caffeine intake stipulated. On arrival, candidates signed Informed Consent, presented their driver licence, and submitted to Breathalyzer® and DrugWipe® 6S, which if either were positive, would result in re-scheduling. Health and drug screening, and psychological and psychosocial assessment lasted until approximately 11:30 with regular rest breaks. Following a standard light lunch and other tasks, participants performed the IGT and driving simulation to conclude the protocol at about 16:15. With participant consent, information from Quebec's licensing authority corroborated participant group assignment.

3.1. Preliminary data treatment and main analytic plan

For the present analysis, the sample was stratified into younger (i.e., 19–28 years) and older (i.e., 29–39 years) subgroups. These age ranges optimally balanced two considerations: the desirability of evenly distributed subgroups, and their sensitivity to ongoing or complete neural maturation (Johnson, Blum, & Giedd, 2009; Shulman et al., 2016). Descriptive analyses were conducted using two-way, age (2) by group (4) ANOVA and *post-hoc* tests to compare risky driver subgroups (i.e., categorized by age) to their age-matched CTL subgroup on sociodemographic data, driving history and alcohol and drug misuse data. Chi-square tests were used for categorical data.

Main analyses on the dependent variables of interest involved planned contrasts using least observed square means derived from the overall 2×4 ANOVA model. Specifically, younger and older drivers of each risky driving group were compared to their age-matched CTLs. Results for each significant contrast are reported as 95% confidence interval for differences (95%CI diff), and alpha corrected to maintain error for inferences at $p \le 0.05$ for each dependent variable of interest. Effect sizes are reported as partial η^2 for simple group effects within the specific age category. To avoid redundancy, age main effects are reported but group main effects are not, as these were reported and interpreted in the parent study (Brown et al., 2016).

4. Results

4.1. Sociodemographic characteristics, substance use and driving history

Table 1 provides frequency and descriptive statistics on all eight subsamples and results of descriptive analyses comparing risky driver groups and CTL group within each age category.

Analyses of MAST scores detected significant elevations in both younger and older drivers in group DWI, and in older drivers in group MIXED. AUDIT score and frequency of days during which ≥5 drinks were consumed in past 90 days (TLFB) were significantly higher in older DWI group. More years of drinking were associated with older age. Greater frequency of self-reported DWI behaviour that had not resulted in arrest was reported by young drivers in group SPEED.

Preparatory sensitivity analyses were carried out prior to main analyses to determine whether co-variance needed to account for sociodemographic differences between driver subgroups and their age matched controls. Significant associations ($p \le 0.05$) had been found between driver group and ethnicity in the parent study, and here between driver group and licensing status, and between age category and family status and revenue. However, no variable was significantly associated with both driver group and age category, thus negating the need for

Table 1
Sociodemographics, substance use, and driving history of the low-risk control group (CTL), driving while impaired group (DWI), mixed group (MIXED), and non-alcohol reckless driver group (SPEED) presented by age subgroups (19–28; 29–39), with comparisons between risky driver groups to their age-matched CTL group.

	CTL		DWI		MIXED		SPEED	
	19–28 (n = 22) M (SD)	29–39 (n = 25) M (SD)	19–28 (n = 16) M (SD)	29–39 (n = 20) M (SD)	19–28 (n = 16) M (SD)	29–39 (n = 11) M (SD)	19–28 (n = 14) M (SD)	29–39 (n = 14) M (SD)
Sociodemographics								
Age	24.3 (2.5)	35.2 (3.1)	24.4 (2.5)	34.3 (3.2)	23.4 (2.8)	34.2 (3.2)	24.4 (2.0)	32.9 (3.0)
Ethnicity other than Caucasian (%)[a]	22.7	36.0	0	20	18.7	9.1	42.9	50.0
Highest level of education								
% High school or less	13.6	8.0	18.8	20.0	37.5	36.4	35.7	14.2
% College or more	86.4	92.0	81.2	80.0	62.5	63.6	64.3	85.8
Family status								
% Single/living alone	81.8	60.0	75.0	65.0	87.5	72.7	71.4	64.3
% Married/living with a partner	18.2	40.0	25.0	35.0	12.5	27.3	28.6	35.7
Income from all sources (last year)								
% 0–≤19,999 $	36.4	16.0	31.3	15.0	50.0	27.3	21.4	21.4
% 20,000—39,999 $	45.5	24.0	37.5	30.0	25.0	27.3	50.0	42.9
% ≥40,000 $	18.2	60.0	31.2	55.0	25.0	45.4	28.6	35.7
Occupation (last 3 years)								
% Full-time or stable part-time job	59.1	84.0	56.3	60.0	56.3	54.5	57.1	71.4
% Students or other status[b]	40.9	16.0	43.7	40.0	43.7	45.5	42.9	28.6
Substance use								
MAST	2.5 (2.0)	2.3 (2.0)	12.9 (7.3)*	29.3 (20.6)*	9.0 (4.6)	16.2 (11.6)*	4.9 (4.4)	3.8 (4.7)
AUDIT	4.8 (4.5)	3.9 (3.0)	8.2 (5.3)	11.4 (9.1)*	7.9 (3.4)	6.6 (6.1)	8.9 (5.6)	4.7 (6.8)
DAST	0.7 (1.6)	0.8 (1.6)	1.5 (1.2)	1.2 (1.7)	2.6 (4.0)	2.0 (4.4)	1.9 (2.2)	1.7 (2.4)
Years of drinking	11.5 (5.8)	19.6 (5.1)	11.3 (3.2)	20.2 (5.3)	9.1 (3.5)	18.7 (3.2)	11.6 (4.2)	18.9 (6.2)
TLFB Days of ≥5 drinks in past 90 days	5.1 (6.9)	1.2 (2.2)	6.4 (8.1)	7.8 (8.8)*	6.2 (6.0)	2.4 (3.6)	8.1 (9.2)	3.1 (7.7)
TLFB Days of drug use in past 90 days	6.0 (19.6)	5.0 (18.5)	3.8 (6.4)	5.6 (19.9)	16.3 (28.3)	0.8 (1.8)	16.4 (26.1)	8.5 (23.6)
Cigarettes/day	0.8 (2.7)	1.2 (3.1)	4.6 (7.0)	7.0 (9.0)*	2.0 (3.7)	7.9 (8.5)*	4.1 (6.1)	1.9 (5.5)
Driving history								
Age of licencing	17.5 (1.7)	18.5 (23.8)	16.9 (1.1))	17.4 (1.8)	17.4 (1.2)	18.6 (3.5)	17.7 (1.1)	19.0 (3.0)
% Currently licenced	100	100	12.5*	15.0*	50.0*	27.3*	92.9	100
Kilometres (1000's) driven (past year)	21.6 (17.1)	18.5 (23.8)	12.0 (12.4)	76.8 (11.2)	10.5 (9.8)	14.7 (17.6)	22.5 (21.5)	22.0 (16.7)
Self-reported impaired driving episodes (past year)	0.6 (1.4)	0.2 (0.8)	2.0 (7.5)	0.9 (2.4)	1.8 (3.8)	2.0 (3.0)	7.9 (14.5)*	2.7 (5.7)

Abbreviations: MAST: Michigan Alcohol Screening Test; AUDIT: Alcohol Use Disorder Identification Test; DAST: Drug Abuse Screening Test; TLFB: Timeline Followback.
[a] Includes Afro-Canadian, First Nations, Asian, Hispanic.
[b] Other status includes retiree, disabled, living in institutional settings or unstable conditions, seasonal worker, unemployment or welfare, homemaker. Group differences were detected by ANOVA for continuous variables and χ^2 for categorical data.
* $p < 0.05$, Bonferroni corrected.

co-varying on sociodemographic variables in subsequent analyses of age by group interaction effects.

4.2. Behavioural risk taking

On mean highway speed (Fig. 1a), an age main effect indicated that younger drivers had higher mean highway speed than older drivers, M = 82.3 km/h, SD = 9.04 vs. M = 78.6 km/h, SD = 9.89; F(1,127) = 4.53, $p = 0.035$, $\eta^2 = 0.03$, regardless of risky driving group membership. Age by group contrasts indicated that group SPEED had significantly higher highway mean speed than group CTL in younger drivers alone, 95%CI diff: 2.68, 19.03; $p = 0.003$, $\eta^2 = 0.39$. On mean merge acceleration (Fig. 1b), an age main effect was not found; however, age by group contrasts indicated that younger drivers in group SPEED showed greater acceleration than group CTL, 95%CI diff: 0.0, 0.41; $p = 0.05$, $\eta^2 = 0.09$. On mean intersection acceleration (Fig. 1c), an age main effect was not detected, but age by group contrasts, indicated that older drivers in group MIXED had greater acceleration than group CTL, 95%CI diff: 0.05, 0.36; $p = 0.003$, $\eta^2 = 0.10$.

4.3. Personality characteristics

On the NEO-FFI Agreeableness scale (Fig. 2a), an age main effect was not detected. An age by group interaction was detected, with younger drivers in group SPEED scoring significantly lower than group CTL, 95%CI diff: −17.8, −0.65; $p = 0.002$, $\eta^2 = 0.11$. On the UPPS Sensation Seeking scale (Fig. 2b), a significant age main effect was detected, indicating that younger drivers scored higher than older drivers regardless of group membership, M = 38.5; SD = 6.36 vs. M = 34.8, SD = 6.35; F(1,130) = 7.28, $p = 0.008$, $\eta^2 = 0.05$. Age by group contrasts revealed that older drivers in group SPEED scored significantly higher than group CTL, 95%CI diff: 0.43, 11.49; $p = 0.027$, $\eta^2 = 0.08$. On the SPSRQ Reward sensitivity scale (Fig. 2c), while an age main effect was not detected, age by group contrasts revealed that older drivers in group MIXED scored higher than group CTL, [95%CI diff: 0.27, 6.50,], $p = 0.026$, $\eta^2 = 0.07$.

4.4. Behavioural tasks of reward sensitivity and cognitive control

On the Stoplight Task, a significant age main effect was not detected, but age by group contrasts (Fig. 3a) revealed that older drivers from group SPEED scored higher than group CTL, [95%CI diff: 0.02, 0.29], $p = 0.021$, $\eta^2 = 0.07$. On the CPT-2 Commission Errors scale, a significant main age effect was not detected. Age by group contrasts (Fig. 3b) indicated that older drivers from group DWI scored higher than group CTL, [95%CI diff: 0.10, 13.64], $p = 0.045$, $\eta^2 = 0.08$. Follow-up correlational analyses were undertaken in group DWI to clarify whether this effect could be explained by alcohol-related factors, such as years of drinking and alcohol misuse severity. A significant relationship between age and years of drinking was found, $r = 0.83$, $p < 0.001$. Moreover, a significant relationship on commission errors with years of drinking was also detected, $r = 0.37$, $p = 0.03$, but not with either the AUDIT or MAST. On the Hit Reaction Time, no significant age main effects or age by group contrasts were detected. Finally, on IGT Decision making under Ambiguity, no significant age main effect or age by group contrasts were detected.

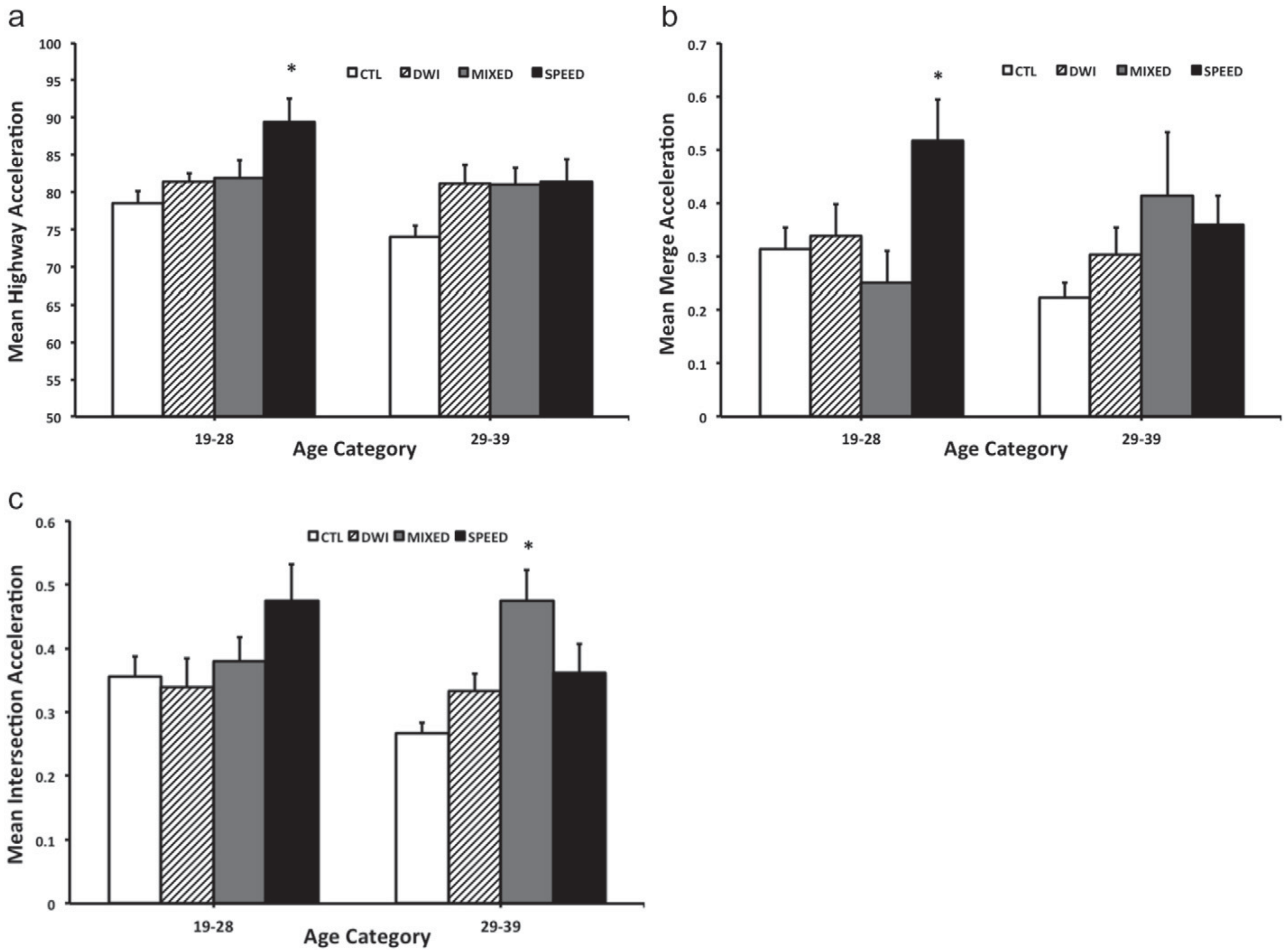

Fig. 1. Comparisons between younger and older drivers of each risky driving group to their age-matched CTLs on: 1a) mean highway speed; 1b) mean merge acceleration; and 1c) mean intersection acceleration. * $p \leqq 0.05$.

5. Discussion

This study builds upon previous investigation of drivers who engage in different forms of risk driving. Its strengths include prospective recruitment of representative age-matched risky-driving samples and low-risk controls, multidimensional analysis of age effects on risk-taking behaviour and accompanying personality features, behavioural task performance, and ecologically valid and experimentally controlled driving-related risk taking via simulation. Our initial examination of age main effects on our dependent variables of interest revealed that both sensation seeking and risky driving, indexed as mean speed, were higher in younger drivers compared to older drivers, independent of driver group membership. These findings are consistent with observations that sensation seeking and risk taking are characteristics of younger age that typically decline over time (Nicholson et al., 2005). Variations with increasing age in sensation seeking, which closely tracks hyper-responsivity in reward systems (Steinberg & Chein, 2015), follows an inverted U pattern that typically peaks between ages 15 to 25 years. At the same time, the influence of the cognitive control system gradually grows (see Steinberg, 2008 for review). Studies of age effects in performance on laboratory risk-taking tasks have produced inconsistent results – possibly due to between-study differences in risk-taking tasks (Defoe, Dubas, Figner, & van Aken, 2015; Shulman et al., 2016). Nevertheless, the contiguous declines in both sensation seeking and risky driving in simulation (i.e., mean speed) with older age found here plausibly validate the impact of the reward system on this laboratory proxy of risky driving (Bella, 2008; Godley, Triggs, & Fildes, 2002; Riermersma et al., 1990). The absence of age differences on other risky-driving measures indicates that additional systems in which age effects are more heterogeneous (e.g., decision making) (Tymula, Rosenberg Belmaker, Ruderman, Glimcher, & Levy, 2013) may be involved. Given the advantages of driving simulation as a controlled, laboratory-based measure of risk taking (Ouimet, Duffy, Simons-Morton, Brown, & Fisher, 2011), more parametric investigation of the explanatory mechanisms related to specific forms of risk taking in the simulator is clearly needed.

The main results of this study supported our over-arching hypothesis that age exerts unique effects in each risky driver group. Starting with the DWI group, consistent with hypotheses, older drivers showed significantly more elevated behavioural disinhibition compared to controls in contrast to younger drivers who did not. While this finding is based on cross-sectional analysis, it suggests incomplete maturation of executive control in older DWI drivers. It is also coherent with trends for greater alcohol misuse in older DWI drivers observed here, and other evidence (e.g., Crews & Boettiger, 2009) positively associating duration and severity of alcohol exposure with severity of impulse control difficulties.

Curiously, poorer cognitive control in older DWI offenders was not accompanied by indices of elevated driving-related risk taking. In other research by our group, young male adult (i.e., mean age $\approx$ 30 years of age) first-time DWI offenders also showed few psychological or behavioural indicators of poorer cognitive control

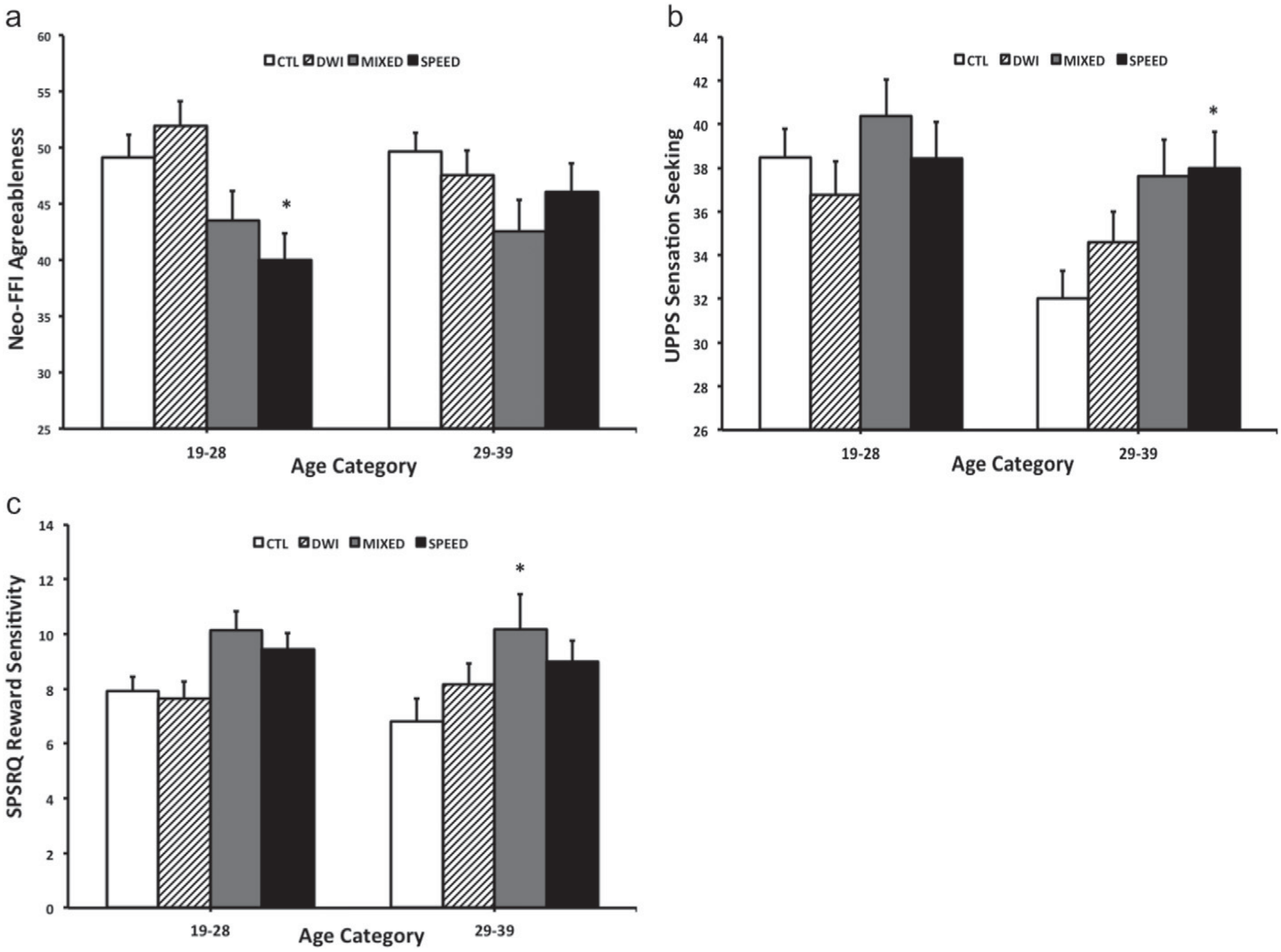

Fig. 2. Comparisons between both younger and older drivers of each risky driving group to their age-matched CTLs on: 2a) Neo-FFI Agreeableness; 2b) UPPS Sensation Seeking; and 3c) SPSRQ Reward Sensitivity. * $p \leqq 0.05$.

(Brown, Ouimet, Nadeau, Tremblay, & Pruessner, 2015). In subsequent analyses, however, we detected structural anomalies in the posterior cingulate cortex (Dedovic et al., 2016), but only when alcohol misuse was relatively low and at levels comparable to that seen in the younger DWI drivers here. The posterior cingulate cortex is a complex brain structure that has been associated with the signaling of environmental change and the need to alter behaviour (Leech, Braga, & Sharp, 2012). Additionally, cortical thinning in this area has been observed to

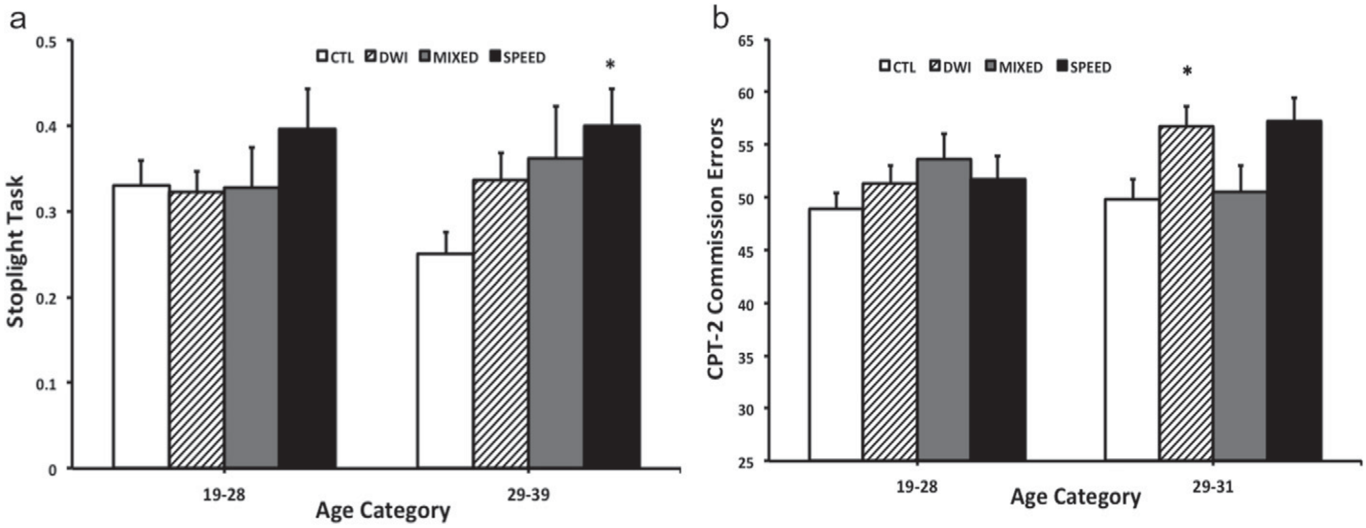

Fig. 3. Comparisons between both younger and older drivers of each risky driving group to their age-matched CTLs on: 3a) Stoplight Task; and 3b) CPT-2 Commission Errors. * $p \leqq 0.05$.

accompany difficulties in anticipating consequences of antisocial behaviour (Cook et al., 2013). These strands of evidence converge in a hypothesis for future testing, namely that older DWI offenders have cognitive control difficulties that contribute to poor regulation over alcohol misuse, while younger offenders possess characteristics that exert a more indirect contribution to DWI risk (e.g., difficulty in altering typical behaviour and/or anticipating consequences of antisocial behaviour).

Among the features related to both hyper-responsivity to reward and fearlessness that characterised the MIXED group in the parent study (i.e., blunted cortisol stress response, reward sensitivity, asocial personality features) (Brown et al., 2016), here we found that both elevated reward sensitivity and risky driving behaviour were distinguishing features in older MIXED drivers. This result deviates significantly from the main effect of age on these measures discussed above, as well as theoretical developmental models of the reward and cognitive control systems (Casey et al., 2008; Steinberg & Chein, 2015). As such, these findings are consistent with our hypothesis that older MIXED drivers do not benefit from normal prefrontal maturation that would predict attenuation of the propensity for risk taking. Interestingly, this feature in older MIXED drivers, and the putative involvement of the orbitofrontal area in the reward system (Bechara, Damasio, Damasio, & Lee, 1999), resembles the worsening age-related declines in emotional decision-making capacities seen in lesion patients with early-age orbitofrontal injuries (Bechara, 2004). More research is needed with the acuity to confirm the involvement of these neural systems (e.g., orbitofrontal cortex, amygdala, stria terminalis system), possibly via imaging.

Findings from the parent study that characterised the SPEED group (i.e., elevated sensation seeking, disinhibition, risky decision making, and marked risk-taking propensities) led us to speculate that the thrill seeking of these drivers was akin to that seen in reward deficiency syndrome (Comings & Blum, 2000). The findings here of elevated driving risk on two measures in younger SPEED drivers, namely highway mean speed and merge speed, are consistent with this view, thus supporting our intuitive hypothesis regarding this age group. Low agreeableness personality in younger SPEED drivers specifically, which was also accompanied by elevated risky-driving behaviour, is consistent with previous results indicating a link between agreeableness and risky driving (Cellar, Nelson, & Yorke, 2000; Dahlen & White, 2006; Starkey & Isler, 2016). Explanations for this association include sensitivity of the agreeableness dimension of the NEO-FFI to: i) poor emotional regulation over anger and frustration in contexts involving constraint, such as rules and regulations (Arthur & Graziano, 1996); and ii) reduced serotonergic system activity (Lesch et al., 1996), which when elevated, may countervail the reward system's influence in promoting risk taking (Daw et al., 2002).

In the older SPEED drivers, unanticipated elevations were found in both the Stoplight Task and the UPPS Sensation Seeking scale. Both measures are sensitive to reward system activity and its association with risk-taking propensity (Bechara et al., 2002; Grant, Brewer, & Potenza, 2006). At the same time, older SPEED drivers lacked indicators of elevated risky driving behaviour that would be expected to accompany dysregulation in the reward system. One explanation for this disconnect is that control of risk-taking propensity exerted by the prefrontal system may be increasing (i.e., risk taking declines), but it is incapable of completely compensating for an overpowered reward seeking system.

There are other possibilities, however. For one, older SPEED drivers may simply not have perceived the simulated driving task as intrinsically rewarding in a way that would evoke risk-taking behaviour. If this is the case, other social factors not directly addressed here, such as norms, risk perception, and the nature of the driving experience (Jafarpour & Rahimi-Movaghar, 2014), may be motivating risky driving on the road. An intriguing alternate hypothesis for future research springs from the observation of a trend toward greater agreeableness in older SPEED versus younger SPEED drivers (i.e., in exploratory analysis; 95%CI diff: 0.90, 13.0; $p = 0.087$). Along these lines, in addition to added behavioural control exerted by the prefrontal system in older SPEED drivers, greater agreeableness may be signaling heightened emotional control and serotonergic system activity that, as noted above, may dampen the influence of the reward system.

5.1. Limitations

This study possessed several noteworthy limitations. Given its secondary analysis nature, prospective power calculations to estimate sample size for subgroup analyses were not undertaken, thus increasing risk of Type 2 error. Drift between age categories was also possible, as some driving violations of older age category participants may have occurred when they were of the age subsumed by the younger age category. Relatedly, all groups exhibited heterogeneity in their risky driving characteristics, with some overlap of key self-reported driving behaviours (e.g., DWI) across high-risk groups. Indeed, the observation that DWI behaviour was most frequent among SPEED drivers may be an artefact of their greater candour in reporting all instances of DWI behaviour without an arrest, and/or their greater frequency of being licensed compared to the other risky driving groups. Indeed, social desirability bias in self-reported DWI behaviour among DWI offenders is common (Chang & Lapham, 1996). At the same time, arrests and convictions for traffic violations are rare relative to their frequency of occurrence (Beitel, Sharp, & Glauz, 2000; Miller et al., 1999). Thus, our use of documented traffic violations for group inclusion favours recruitment of more extreme and persistent offenders from within each risky-driving population. The study's cross-sectional approach does not permit causal inferences. Biological corroboration of participants' self-reported sober state is a strength of the protocol compared to sole reliance on self-report. Nevertheless, it is conceivable that some participants could have been under the residual long-term effect of prior substance use. Finally, caution is warranted in generalizing the findings to female drivers who were not sampled, and to jurisdictions whose traffic laws and enforcement patterns differ substantially from those in Quebec.

5.2. Conclusion

The results of this secondary analysis underscore the complex multidimensional interactions influencing driving related risk taking. They also suggest that unique developmental processes predominate in distinct forms of risky driving behaviour at different ages. Practically, the design of more effective interventions may require tailoring based not only on risky-driving preference, but age and neurodevelopment as well. Future prospective confirmatory study is needed using: i) larger samples of risky drivers, including both males and females, to increase sensitivity of analyses and the generalizability of the findings; ii) additional age stratifications to more finely track key neurodevelopmental processes; and iii) levels of analysis with the acuity to detect and confirm the involvement of putative social, personality, cognitive and neural (e.g., via fMRI) systems involved in the risk taking of these driving groups.

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