Fonds de recherche Société et culture Québec

Rapport de recherche

PROGRAMME ACTIONS CONCERTÉES

# Mécanismes multidimensionnels de la conduite à haut risque


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PARTIE A – CONTEXTE DE LA RECHERCHE

## Problématique

Traffic crashes are the 9th leading cause of disability-adjusted-life years lost worldwide, with current projections placing them 3rd by 2020 (Sleet and Branche, 2004, Sleet et al., 2004). In 2006, 2,889 Canadians died from motor vehicle crashes and 199,337 were injured, of which 17,000 were serious enough to cause longstanding disability (2010). Significant progress has been realized over the past decades in reducing some sources (e.g., drinking driving, neglect of seat belt use) of traffic-related morbidity (Hingson and Winter, 2003, NHTSA, 2008). Nevertheless, the global health, social and economic costs remain so intolerably high that the UN General Assembly (A/64/L.44/Rev.1) proclaimed 2011-2020 as a "Decade of Action for Road Safety" in order to spur further reductions.

Risky driving accounts for most fatal crashes (Burian et al., 2002), which include speeding, driving while impaired (DWI), neglect of seat belts and other risky driving practices. Drivers who repeatedly engage in one or multiple types of risky driving behaviours are more likely to share certain individual characteristics. This association has provoked intense interest in the so-called "high risk driver" population as a specific target for investigation, detection, and intervention (Begg and Langley, 2004, Beirness, 1991, Bina et al., 2006, Blows et al., 2005, Chen, 2009, Cooper et al., 2003, Dula and Geller, 2003, Eby and Charles, 2004, Evans and Wasielewski, 1983, Fear et al., 2008, Fillmore et al., 2008, Hatfield and Fernandes, 2009, Iversen, 2004, Iversen and Rundmo, 2002, Jonah, 1997, Jonah et al., 2001, Lonczak et al., 2007, Oltedal and Rundmo, 2006, Schwebel et al.,

2007, Schwebel et al., 2006, Ulleberg and Rundmo, 2003, Vassallo et al., 2008, Vassallo et al., 2007, Williams et al., 2006). In her review, Vézina (Vezina, 2001) operationalized the high risk driver (HRD) as an individual who has engaged in 3 or more distinct high-risk driving events within a 2-year period. These events include a road or criminal conviction, license suspension, reported crash, first DWI conviction with blood alcohol level (BAC)>150mg/100ml or involving refusal to provide breath sample, DWI recidivism, and driving with a suspended licence. She also speculated that the HRD population is comprised of distinct subgroups that share common behaviours, attitudes and motivations. Clarification of these subgroups, and our ability to better identify them, would be a critical precursor for earlier and more targeted intervention. A decade's worth of HRD research since the Vezina report, however, has failed to satisfactorily attain this capacity (LaBrie et al., 2007). The two lethal corollaries of this gap are: a) reliable detection of HRDs is only possible after a driver has engaged in multiple life threatening events (e.g., crashes, speeding, DWI); and b) the data to inform evidence-based interventions for these individuals are unavailable.

Our previous research (Bouchard et al., 2012, Brown et al., 2005, Couture et al., 2008) provides evidence for two explanatory pathways to persistent HRD. Decision-making deficits have differentiated between distinct offender groups. Whether decision-making impairments and/or patterns underlie different forms of HRD behaviours requires further investigation. We have also discovered that dysregulation in a homeostatic arousal system, whose marker (salivary cortisol) is readily accessible, is associated with DWI and crash risk. The variance in HRD-related behaviour accounted for by both pathways is considerably greater than seen

with most other commonly used correlates. Consistent with the neuropsychological paradigm, these results speak to the promise of research into neural-level processes as a way to better understand how personality and other factors actually lead to HRD, rather than simply being correlated with it, and to develop targeted interventions, something that National Highway Traffic Safety Administration has recognized and expressly called for (Eby and Charles, 2004).

## Objectifs poursuivis et hypotheses

### Objective 1: Characterization of main HRD groups by nature of their cognitive and neurobiological characteristics

In separate studies of different HRD groups, our work indicates that markers of two distinct neural processes explain significant proportions of the HRD variance. No studies to date have simultaneously tested these two processes in risky behaviour generally or HRD specifically.

**$H_{1a}$:** HRDs exhibit decision-making processes that favour immediate gains over later losses compared to normal drivers;

**$H_{1b}$:** HRDs exhibit dampened arousal to stress compared to normal drivers

Two competing assumptions underlie the HRD research and prevention: a) a common causal pathway underlies all HRD behaviour (e.g., Jonah, 1997); and b) engagement in dissimilar HRDs (e.g., speeding versus DWI) reflects the predominance of different underpinnings (e.g., Fernandes et al., 2007). Clarification of which assumption is supported is vital for substantiating the need for targeted HRD intervention strategies.

**$H_{1c}$:** DWIs (HRDs more prone to drink driving) show greater immediate gain oriented decision-making than Speeders and Normal drivers;

$H_{1d}$: Speeders (HRDs more prone to speeding) show lower arousal to stress than DWIs and IGT drivers.

**Objective 2: Identification of homogeneous subgroups based upon putative cognitive and neurobiological processes underlying risky behaviour** We have argued that clarification of HRD subgroups anchored upon distinct explanatory pathways could explain more of the variance in HRD and thus provide guidance for developing targeted interventions to interrupt these pathways.

**$H_{2a}$:** HRDs exhibiting flawed decision-making that favours immediate gains over later losses show greater risk taking behaviour compared to either HRDs who do not or CTL drivers;

**$H_{2b}$:** HRDs exhibiting reduced arousal to stress show greater risk taking behaviour compared to either HRDs who do not or CTL drivers.

**Objective 3: Validation of the clinical significance of these processes by observation of HRD under experimentally manipulated simulated driving and risk taking conditions** Here we examine how between-group differences are expressed behaviourally in a naturalistic way by exposing groups to simulated driving and risk taking scenarios that test putative neural processes to specific HRD behaviours. We use risk taking simulation tasks that challenges drivers to make decisions and manoeuvres where both risk taking and safety are rewarded, but outcomes are uncertain.

## PARTIE B – PISTES DE SOLUTION EN LIEN AVEC LES RÉSULTATS

### SAAQ priorities

This study targets needs expressed by Axis 5 of the FRSQ-FQRSC-SAAQ Request for Applications that funded it. Axis 5 explicitly asks to characterize HRD offenders, identify subgroups, and gain greater understanding of factors that motivate this behaviour to guide evidence-based interventions development. This study aligns precisely with these objectives. It is also inspired by the other premise of Axis 5, namely, that if we knew more about "motivational" factors underlying HRD behaviour, we would be better equipped to design targeted interventions capable of interrupting them. We explore two powerful candidate motivational systems based upon our preliminary work. Our research team also counts as team members representatives from the Société d'assurance automobile du Québec (Ms. Lynn Vezina) and the Association des centres de réadaptation en dependence du Québec (Ms. Candide Beaumont) who administrate the DWI evaluation program. Their input in our research agenda is a core value of this team, and we meet with them frequently to discuss our common research projects (we are engaged in several projects commissioned by them) and their future research needs. In response to their input, as well as that of DWI and HRD clinician/evaluators from across Canada based upon a survey conducted by team members from the Traffic Injury Research Foundation, we have extended the scope of our research to include non-DWI related HRD. The evaluators' interest in having better, more valid assessment technologies is a principal target of this study.

## Targeted interventions

Our past work into DWI recidivism using both cognitive and neurobiological markers has produced evidence for a male-specific pathway to DWI recidivism risk involving flawed decision-making, reward sensitivity as well as other self-regulatory deficits [see (Brown et al., 2013a, Brown et al., 2009b) for our recent reviews]. The present study will test the distinctness of pathways underlying different forms of HRD, an open question at present. If these are uncovered, it will indicate the need to further tailor interventions based on type of HRD.

## Detection

Our ability to characterize these individuals by their associated psychosocial attributes could assist in their detection during driving evaluation protocols. Finally, it is also possible that the neuropsychological assessment technologies we use here (e.g., the Iowa Gambling Task) could be adapted for detection of such drivers, as is occurring in fitness-to-drive evaluations of cognitive capacities in aging and neural health. In sum, this knowledge will empirically inform: i) development of more accurate detection technology for identifying high risk drivers; ii) targeted interventions matched to HRD subgroups, iii) investigation of targeted treatment effectiveness in random controlled trials, initiatives our team have undertaken successfully in the past (Brown et al., 2010a, Brown et al., 2002, Brown et al., 2002/7).

## Policy

It is imprudent scientifically to promote preliminary results as rationales for altering provincial or national HRD policies. Nevertheless, the findings - if our hypotheses are supported - could challenge entrenched beliefs underpinning current HRD policy in traffic safety. Open communication channels between the knowledge users and traffic safety administrators and our team will introduce the findings into the discourse concerning the updating of policies.

## Training and capacity building

An additional tangible, near-term outcome of this study is the training of new investigators. There is growing recognition of the advantageousness of multidisciplinary, multi-method research for resolving complex health issues. This paradigm is an overarching theme underlying our CIHR transdisciplinary team into DWI. Nevertheless, the current capacity for multidisciplinary research into traffic safety is extremely limited in Quebec as elsewhere. The proposed study combines the disciplines of psychology, human factors, simulation engineering and informatics, and applied neuroscience with both correlational and experimental methodologies. This is a rich medium to develop new researchers capable of conducting multidisciplinary traffic safety investigations. Our team recruited two graduate students from McGill who worked on this study for their theses and research training. Two new researchers represent a substantial increase in Quebec's capacity for conducting multidisciplinary traffic safety research.

## Innovation

The paradigmatic shift occurring in the risk taking research involves

movement away from using static psychosocial or personality taxonomies (e.g., impulsivity, sensation-seeking) to the exploration of core multilevel and explanatory processes (e.g., neurobiological and neurocognitive behavioural pathways to motivation) in dynamic risk-taking situations. Applied to traffic safety, this approach promises the high resolution needed for differentiating low- and high-risk individuals in a heterogeneous population. The driving area is moving inexorably in this direction, as general theories of driving risk are increasingly contextualized within individual cognitive competency. Pragmatically, this approach engenders functional behavioural testing and quasi-experimental and experimental methodologies that can better infer causal processes between an individual's thinking, mood and behaviour. The HRD research has yet to adopt this integrative multidimensional framework.

Consequently, one major outcome of this study is innovation in HRD research, as we shift to an investigatory paradigm that aligns with contemporary scientific trends at work in other risky behaviour domains. Fresh ideas in the discourse about HRD are needed, and apparently welcomed. Evidence for this latter contention includes: invitations to our CIHR transdisciplinary team to debrief the Canadian Parliament, the SAAQ, the ACRDQ and Transport Canada concerning the implications of our neurocognitive findings to DWI policy; being commissioned to report to Quebec's Ombudsman regarding current DWI detection technologies and their implications for social justice; and invitations to contribute to encyclopaedic and specialized knowledge repositories in the area of traffic safety prevention (e.g., Brown et al., 2013a, Brown and Ouimet, 2012, Brown et al., 2013b) .

## Limits to generalizability of the results

This study acknowledges a number of limits in tis generalizability. It focuses on male HRD, leaving uncertain the applicability of the results to female HRD. The sampling is restricted, making replication of the findings a necessity prior to making firm statements about the external validity of the findings. Finally, membership in the HRD population is determined by enforcement of existing laws. Hence, sampling, and its generalizability to other jurisdictions, is vulnerable to jurisdictional differences in law, enforcement, as well as other local and individual conditions, including availability of transportation options, environmental, socioeconomic and cultural distinctions, etc.

## Anticipated main messages from this research

HRD drivers are heterogeneous in what motivates their risky behaviour. Different subgroups that share distinct motivational pathways to risky behaviour are important to discern. Their identification promises to lead to more individualized prevention strategies designed specifically to disrupt these distinct pathways and more effectively reduce HRD risk.

PARTIE C - MÉTHODOLOGIE

**Design** A quasi-experimental design with purposeful recruitment to compare HRD with non-HRD samples. *Sample:* Male drivers aged 18-40. Non-HRD controls (CTL; n=49) and HRDs (n=92). *Inclusion criteria for HRD:* Using Vezina's operationalization (Vezina, 2001), a minimum of 3 distinct events within a 2-year period (i.e., road or criminal conviction, license suspension, reported crash, first DWI conviction with blood alcohol level (BAC)>150mg/100ml, refusal to provide breath sample, recidivism, driving with a suspended licence). *Inclusion criteria for CTL:* Not fulfilling HRD criteria, no DWI conviction, and no more than one speeding citation in the last 5 years. *Participant exclusion criteria:* Ill health, BAC >.01 at interview, psychoactive substance use in past 48 hours.

**Analytic overview** Independent variables: i) Main groups: HRD vs. CTL; ii) Sub-groups: Speed HRD, DWI, and Hybrid (mixed). Main dependent variables: a) decision-making under ambiguity and decision making under risk as measured by the Iowa Gambling Task); b) emotional arousal to stress as measured by salivary cortisol reactivity following a psychosocial stress [$\square g$ cortisol/100 $ml$); c) Risky behaviour during a 30-minute simulated driving task (mean speed, maximum speed, speed variability). Other measures such as the AUDIT, MAST and the DAST measured severity of negative consequences and symptoms of substance abuse, the Timeline Followback for risking drinking episodes, and self-report on drink-driving behaviour, among others. Statistics used for main analyses were planned comparisons, correlation, ANOVA, and ANCOVA. For this report, only measures and analyses relevant to the main hypotheses are described here. The interested reader may refer to the annexes for more detailed methodological description.

PARTIE D - RÉSULTATS

## Sample

Table 1 summarizes the demographic, substance use and driving backgrounds of the sample by subgroup designation. Comparisons between CTLs and HRDs revealed significant ($p \leq .05$) differences on the following variables: AUDIT, MAST, average number of weekly drinks, number of days when more than 4 drinks were consumed (i.e., high-risk drinking), number of DWI convictions lifetime and major driving violations, kilometers driven in the past 12 months, the self-reported number of times of driving in the two hours after drinking 4 or more glasses of alcohol in the past 12 months, and the number of significant crashes (over $1500 in damage) over the past 5 years. While all CTLs (100%) had a valid driver license, only 47% of HRDs did, with 37% having a suspended or revoked license and 15.2% not holding a license for other reasons.

| | CTL | | DWI | | Hybrid | | Speed HRD | |
|---|---|---|---|---|---|---|---|---|
| | M | SD | M | SD | M | SD | M | SD |
| Age | 29.94 | 6.12 | 29.97 | 5.60 | 27.69 | 6.25 | 28.79 | 4.93 |
| Highest level of education completed | 15.12 | 2.34 | 14.78 | 2.32 | 13.62 | 2.64 | 15.10 | 2.85 |
| AUDIT | 4.39 | 3.78 | 10.00 | 7.59 | 7.19 | 4.62 | 6.69 | 6.41 |
| MAST | 2.45 | 2.25 | 25.00 | 31.43 | 12.31 | 10.78 | 4.28 | 4.42 |
| DAST | 1.06 | 2.50 | 1.32 | 1.56 | 2.42 | 4.18 | 1.83 | 2.22 |
| Average number of drinks/week | 4.05 | 4.29 | 7.29 | 6.51 | 5.40 | 4.77 | 6.80 | 7.51 |
| Days in past 90 when drank 4+ | 2.94 | 5.22 | 7.24 | 8.25 | 4.46 | 5.47 | 5.59 | 8.54 |
| Number of DWIs lifetime | .00 | .00 | 1.89 | 1.07 | 1.08 | .39 | .00 | .00 |
| Number of major driving violations (lifetime) | 1.29 | 1.63 | 8.59 | 26.73 | 7.00 | 6.42 | 10.55 | 6.59 |
| Number of car crashes ($1500+) past 5 years | .18 | .57 | .49 | .69 | .65 | .75 | 1.00 | 1.54 |
| KM driven last 12 months | 19157.14 | 20727.37 | 9402.97 | 11670.79 | 12634.62 | 13474.09 | 21996.55 | 18604.44 |
| Number of times last 12 months drove after drinking 4 or more | .33 | 1.11 | .86 | 2.49 | 1.88 | 3.50 | 4.34 | 8.56 |

Table 1. Characteristics (means [M]; standard deviations [SD]) of subgroups: Non-HRD controls (CTL; n = 49), alcohol-related high-risk drivers (DWI; n = 37), mixed (both alcohol and speed related HRD; n = 26) and speed-related HRD (n = 29).

## Results of hypothesis testing

**Hypothesis 1a: HRDs exhibit decision-making processes that favour immediate gains over later losses compared to CTL drivers.**

The Iowa Gambling Task (Bechara et al., 2005a) assesses advantageous (rejecting small immediate gains for overall greater gain) and disadvantageous (preferring small immediate gains despite overall greater losses) decision making. Measures on two subtypes of decision making were used, decision making under ambiguity, when outcome probabilities are unknown, and decision making under risk, when outcome probabilities are known. Poor performance on either has been linked to risk taking and problem behaviours such as substance abuse, pathological gambling, criminal behaviour and DWI (Bechara, 2003, Kasar et al., 2010a, Maldonado-Bouchard et al., 2012, Yechiam et al., 2008). Separate ANOVAs compared performance between HRD and CTL groups on decision making under ambiguity (HRD mean = .78; SD = 7.15 vs. CTL mean = 2.06; SD = 6.00) and under risk (HRD mean = 7.82; SD = 10.62 vs. CTL mean = 7.49; SD = 10.49), but neither showed significant difference, $p > .05$.

**Hypothesis 1b: HRDs exhibit dampened arousal to stress compared to CTL drivers.**

Salivary cortisol reactivity following exposure to a psychosocial stress (i.e., mental arithmetic is a reliable objective neurobiological measure of arousal. In past research by our research group, salivary cortisol reactivity was found to be lower in DWI recidivists compared non-DWI controls (Couture et al., 2008). Repeated measures ANOVA revealed a significant Time main effect ($F(2, 276) = 24.61$; $p < .001$). This indicates that for both groups, cortisol reactivity was significantly different at each 15-minute interval following stress exposure. Additionally, a trend for a Group X Time interaction ($F(2,276) = 2.56$; $p = .086$) was found. *Post hoc*

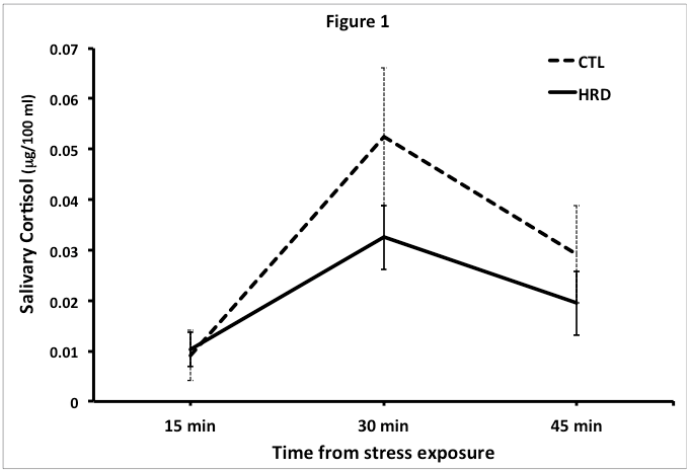


Figure 1 Salivary cortisol reactivity profile of HRD and CTL groups at 15-minute intervals following exposure to psychosocial stress.

tests indicated increase in cortisol reactivity from 15 to 30 minutes tended to be greater in the CTL group compared to the HRD group, $F(1,138) = 4.0$; $p = .048$.

**Hypothesis 1c: DWIs show more disadvantageous decision making than Speeders and CTL drivers.**

Figure 2 depicts performance by CTL, DWI and Speed HRD groups on decision making under ambiguity and under risk. Planned comparisons contrasted DWI participants to Speed HRD on the Iowa Gambling Task. Significant differences between DWIs and Speed HRDs were detected ($t = -2.38$, $df = 137$; $p = .019$) but in the opposite direction than hypothesized; Speed HRDs showed more disadvantageous decision making under ambiguity than DWIs. No differences in decision making between DWIs and CTLs were found, however. Exploratory analysis indicated that Speed HRDs showed significantly poorer decision making under ambiguity compared to all other groups combined ($t = 2.69$, $df = 137$; $p = .008$), that included the Hybrid group, and trended to better decision making under risk compared to all other groups combined (-1.76, $df = 137$; $p = .081$).

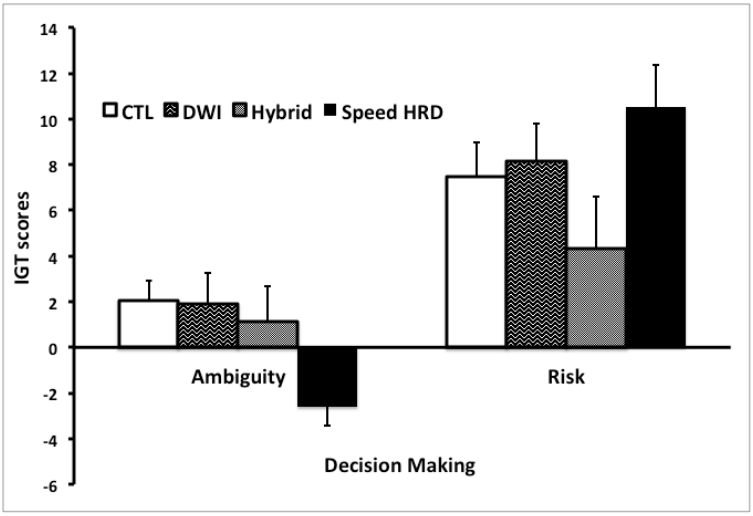


Figure 2. Iowa Gambling Task (IGT) performance on decision making under ambiguity and under risk in CTL, DWI, Hybrid and Speed HRD groups

**Hypothesis 2a: HRDs exhibiting disadvantageous decision-making that favours immediate gains over later losses show greater risk taking behaviour compared to either HRDs who do not or CTL drivers.**

In preparation for testing this hypothesis, performance in driving simulation was compared between groups. Three driving simulation parameters associated with driving risk (Ouimet et al., 2010b) were considered: mean speed, speed variability, and maximum speed. Figure 3 depicts these data. ANOVA on these parameters revealed significant group differences on mean speed ($F(3,136) = 7.50$; $p < .001$), speed variability ($F(3,136) = 8.89$; $p < .001$) and maximum speed ($F = 12.05$, $df = 3, 136$; $p < .001$). *Post Hoc* tests revealed that Speed HRDs exhibited more risky driving behaviour than all other groups on speed variability and maximum speed, $p \leq .001$, and compared to CTLs and DWIs on mean speed, $p < .05$. DWIs exhibited greater mean speed and maximum speed than CTLs, $p < .05$. We conclude from these results that Speed HRDs show the greatest propensity for risky driving behaviour compared to CTLs and the other HRD groups.

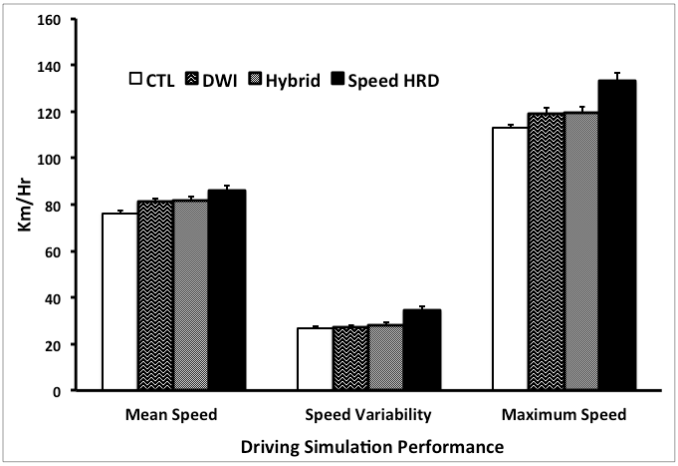


Figure 3. Performance in driving simulation as measured by mean speed, speed variability and maximum speed in CTL, DWI, Hybrid and Speed HRD groups.

Correlational analyses then tested the relationship between decision making on the Iowa Gambling Task and risk taking behaviour in driving simulation in DWI, Hybrid, HRD and CTL groups. Two significant relationships emerged. In CTLs, a significant positive correlation was detected between decision making under risk and speed variability ($r = .401$, $p = .004$), indicating that speed variability was higher in CTLs who showed more advantageous decision making under risk. In Speed HRDs, a significant negative correlation was detected between decision making under ambiguity and mean speed ($r = -.416$, $p = .028$), indicating that mean speed (i.e., risky driving) increased in Speed HRDs when decision making under ambiguity was poorer (i.e., more disadvantageous).

**Hypothesis 2b: HRDs exhibiting reduced arousal to stress show greater risk taking behaviour compared to either HRDs who do not or CTL drivers.**

Testing this hypothesis was preceded by examination of the relationships between cortisol reactivity and risky simulated driving behaviour in CTLs and HRDs. A significant positive correlation between cortisol reactivity and risky driving was found in CTLs, specifically speed variability ($r = .288$, $p = .045$), but not in the

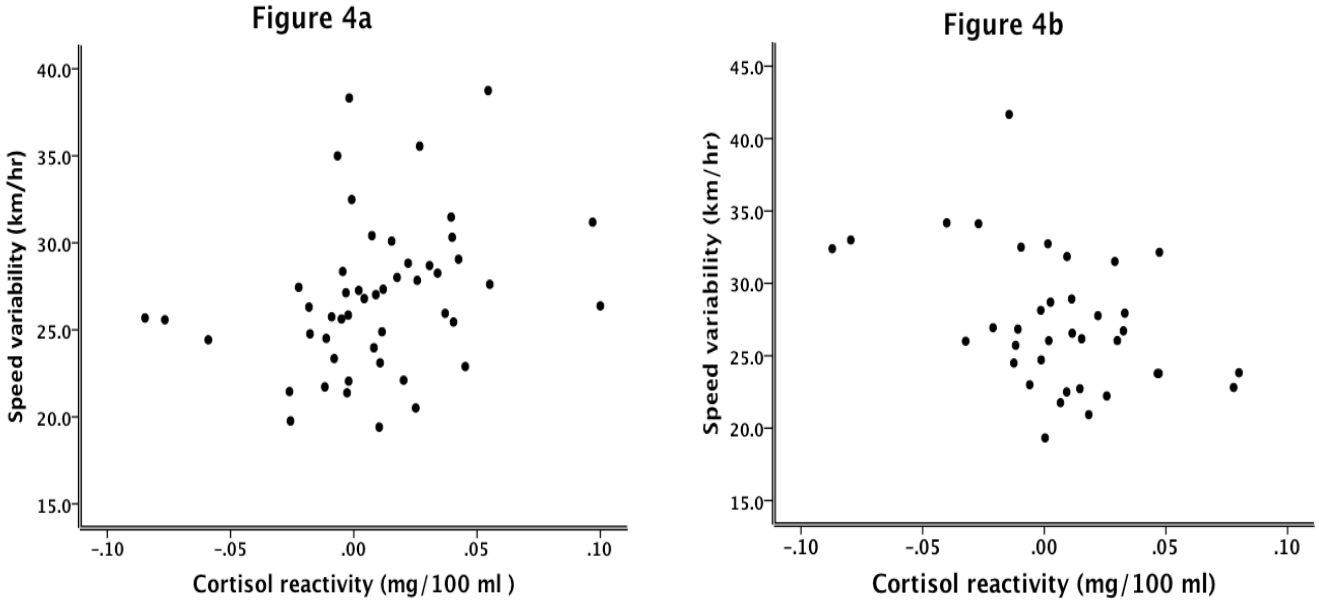


Figure 4. The relationship between cortisol reactivity at 15-minutes after stress exposure and speed variability in CTLs (a) and DWIs (b).

aggregate HRD group. When HRDs were split into DWI, Hybrid and HRD subgroups, however, a significant negative relationship emerged between cortisol reactivity with speed variability in the DWI group ($r = -.425$, $p = .009$). This indicated that as cortisol reactivity diminished, risky driving behaviour increased, an apparently distinct pattern. Figures 4 a, b depict these relationships.

ANCOVA was then undertaken with speed variability as the dependent variable, group (CTL, DWI) as the independent variable, and cortisol reactivity as a covariate. A significant cortisol reactivity X group interaction was found, $F (1, 82) = 12.015$, $p = .001$, indicating that the slopes of the relationship between speed variability and cortisol reactivity differed significantly between groups.

## Discussion

The marked heterogeneity in the characteristics of high-risk drivers continues to frustrate efforts to understand and appraise individual traffic safety risk. Hence, when we took high-risk drivers as a group to investigate dysregulation in two neurobiological mechanisms (decision making and arousal to stress) associated with many forms of risky behaviour, the results were not conclusive. In contrast, our subgroup analyses based upon involvement in either alcohol (DWI) or non-alcohol (i.e., speeding primarily) related offences yielded more intriguing results.

The first main finding was that disadvantageous decision making was unique to speed-related high-risk drivers compared to DWI or normal drivers. The findings also indicated the practical meaning of this result: in speed-related high-risk drivers, the magnitude of their disadvantageous decision making was directly associated with the extent of their engagement in risky driving simulation behaviour. This is a novel finding for the field.

The second main finding was that DWI drivers showed a unique pattern of arousal to stress. This pattern was also associated to the extent of their engagement in risky driving simulation behaviour. These results extend previous research by us and others linking reduced arousal to stress to membership in high-risk groups (Brown et al., 2005, Couture et al., 2008; van den Bos, 2013). These new findings signify that reduced cortisol reactivity is associated with greater propensity for risky driving behaviour observed *in vivo*. In conclusion, we content that like other risky behaviours, high-risk driving has neurobiological underpinnings. Moreover, in support of our over-arching contention, distinct neurobiological processes contribute to different forms of high-risk driving behaviour.

## PARTIE E - PISTES DE RECHERCHE

These finding are groundbreaking. Hence, we feel it behooves us to seek replication of them in future investigations to establish their reliability. At the same time, evidence for distinct neurobiological pathways to different forms high risk driving behaviour offers several tantalizing opportunities for future research. First, there is sexual dimorphism in the linkage between many neurobiological processes and behaviour (van den Bos, 2013). Hence, replication of this study with female drivers is essential to clarify the generalizability of the findings to this growing and increasingly crash-involved driver population.

Second, we now have an empirical basis upon which to guide our investigation and development of more effective and individualized HRD prevention strategies. The objective neurobiological processes that this study has linked to risky driving behaviour may form the basis for future development of improved risk assessment protocols unbiased by the vulnerability of self-report questionnaires to bias. We continue to analyze these data to clarify the behavioral correlates of these neurobiological processes in order to begin the task of more accurately identifying drivers prone to risk taking behaviour.

Finally, decision making and arousal to stress are stable neurobiological processes. Nevertheless, their identification promises development of individualized intervention. Motivational Interviewing is found to activate brain regions involved in decision making. Moreover, interventions exist that focus on helping individuals to use more advantageous decision-making strategies. Future research is needed to determine whether individuals with decision-making and emotional information processing deficits can selectively benefit from such interventions.

PARTIE F - RÉFÉRENCES ET BIBLIOGRAPHIE

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## Annexe 1: L'état des connaissances sur la question

A brief critical review of the HRD research

Better understanding of HRD has been a topic of intense research interest for decades. Beyond having access to a vehicle and the propensity to drive it, descriptive research has consistently uncovered significant associations between different forms of HRD and younger age, male sex, substance misuse, hostility, and sensation seeking and impulsivity personality features (e.g., Arnett, 1996, Begg and Langley, 2004, Beirness et al., 2002, Dahlen et al., 2005, Hatfield and Fernandes, 2009, Iversen and Rundmo, 2002, Jonah et al., 2001, Lonczak et al., 2007, Oltedal and Rundmo, 2006, Romano et al., 2008, Schwebel et al., 2006, Ulleberg and Rundmo, 2003, Williams et al., 2006, Schuman et al., 1967, Evans and Wasielewski, 1983, Fillmore et al., 2008, Franques et al., 2003, Hoyle, 2000, Hoyle et al., 2000, Jonah, 1997, Rajalin, 1994, Steinberg, 2007, Vezina, 2001, Smart and Vassalo, 2005, Fernandes et al., 2010, Fernandes et al., 2007), but its correlational nature leaves causality unaddressed. Several theoretical models have been proposed to understand risky driving, including Zero Risk, Risk Homeostasis, and Utility Maximization (Eby and Charles, 2004). These theories have been useful for better grasping sporadic risk taking in the general population but appear less relevant for understanding the persistent and more malignant form of risk-taking that seems to characterize the HRD population. A more germane approach, consistent with both Jessor's Problem Behaviour Theory and Zuckerman's Sensation Seeking Model, posits that features like sensation seeking and impulsivity represent common and stable personality underpinnings of a generalized form of risk taking (Fillmore et al., 2008, Husted et al., 2006, Jonah, 1997, Beirness et al., 2002). These models, however, do little to explain why HRDs may engage in some but not other HRD behaviours (Fernandes et al., 2010, Fernandes et al., 2007). More recently, studies have begun applying the Five Factor Model of personality to HRD (Dahlen and White, 2006, Hubicka et al., 2010), but these are few in number and inconclusive. Another approach has been to explore data to discern subgroups (typologies) with more homogeneous characteristics within the HRD population (Bjork et al., 1994, LaBrie et al., 2007, Wells-Parker et al., 1986, Wieczorek and Miller, 1992, Ball et al., 2000, Ulleberg, 2001), but these have been empirical, atheoretical, or based upon alcoholism typologies which may not be relevant for most HRDs (Couture et al.). Overall, the aggregate of these efforts is a failure to significantly overcome a fundamental problem plaguing HRD research and policy: the heterogeneity of the driving population (Vezina, 2001, Nochajski and Stasiewicz, 2006). Based upon available assessment approaches, about 50% of HRD drivers are completely indistinguishable from normally adjusted drivers (Wilson, 1992, Vezina, 2001).

This shortcoming has implications for intervention as well. Current intervention programs are influenced heavily by deterrence (e.g., increased and more reliable enforcement and severe of penalties) and planned behaviour (e.g., media announcements and celebrity endorsements, shift in normalized behaviour, heightened perception in probability of arrest) theories (Foss, 2007). While there is good evidence that these approaches have increased traffic safety in the general driver population, they appear less effective in the HRD population they specifically

target (Ulleberg, 2001, Ulleberg and Rundmo, 2003, Marques et al., 1998, LaBrie et al., 2007). In part, this limitation is attributable to their "rational choice" perspective, which may be more relevant to the general driver population than to high-risk groups. Current thinking points to the importance of situational and cognitive contingencies (e.g., perceived benefits of committing infractions under certain circumstances; peer influence) and self-regulatory capacities (e.g., decision-making) as crucial motivators of high-risk behaviour that are not adequately accounted for by the aforementioned theories (Piquero and Tibbetts, 1996, Bechara, 2005, Gardner and Steinberg, 2005, Dastrup et al., Domingues et al., 2009). Not all HRDs engage in all forms of HRD behaviour (Fernandes et al., 2010, Fernandes et al., 2007, Smart and Vassalo, 2005). Important distinctions between HRDs can already be made. Alcohol misuse in DWI offenders represents one distinction which increases the probability of certain neurocognitive and behavioural consequences (e.g., Fein et al., 2006/9, Crews et al., 2004/2, Parsons, 1983, Ouimet et al., 2007, Fillmore et al., 2008, Fillmore et al., 1998, Fillmore et al., 2009, Brown et al., 2009a) compared to other HRD groups (e.g., street racers, speeders) where alcohol misuse is not the sentinel feature (Vingilis, 2010). These distinctions, and those underlying other potentially meaningful subgroups, argue against universal prevention and intervention HRD strategies (Fernandes et al., 2010, Fernandes et al., 2007, LaBrie et al., 2007, Ulleberg and Rundmo, 2003).

There are both methodological and conceptual reasons for the failure of the HRD research to disentangle the perplexing heterogeneity in the HRD population. Methodological shortcomings include over-reliance on data from self-reported questionnaires (e.g., the Barratt Impulsivity Scale, Sensation Seeking Scale [SSS], self-reported risky behaviour). While unobtrusive to collect, these data are vulnerable to subjectivity, social desirability, and shared method variance (e.g., one self-report measure of risk-taking behaviour correlated with another). Moreover, the associations between sociodemographic and personality measures and HRD have been typically modest in strength (Dahlen and White, 2006, LaBrie et al., 2007, Llewellyn, 2008, Arthur and Graziano, 1996), limited in their explanatory or predictive power (Chang et al., 2002, Corbett, 2001, Fernandes et al., 2007, Macdonald and Mann, 1996), and inconsistently linked to actual driving behaviour (Corbett, 2001, Ivers et al., 2009, Rothengatter, 2002, Paris and Broucke, 2008).

Conceptual shortcomings are particularly noteworthy. The so-called "psychometric paradigm" (Llewellyn, 2008) focuses on associations between personality traits and risky behaviors and represents the most pervasive approach to investigation of both risky behaviour and HRD. Of all the personality features associated with HRD that have been investigated in this way, the most compellingly consistent are sensation seeking and impulsivity (Dahlen et al., 2005, Eensoo et al., 2005, Field and O'Keefe, 2004, Fillmore et al., 2008, Richer and Bergeron, 2009, Stanford et al., 1996, Zimmermann, 2010, Arnett, 1990, Dahlen and White, 2006, Desrichard and Denarié, 2005, Donovan et al., 1985, Fernandes et al., 2007, Franques et al., 2003, Hatfield and Fernandes, 2009, Iversen and Rundmo, 2002, Jonah, 1997, Jonah et al., 2001, Lonczak et al., 2007, McMillen et al., McMillen et al., Reynolds et al., 1991, Schwebel et al., 2007, Schwebel et al., 2006, Beirness et al., 2002). Surprisingly, despite the ubiquitous association between sensation seeking (mostly measured by the SSS) and risk taking, it is generally weak and fails to account for other motives risk takers give for their own behaviour. It has

also been criticized for being tautological, as items of SSS refer to specific risky behaviours rather than personality *per se* (see Llewellyn, 2008 for review). Impulsivity for its part is generally understood as involving the tendency to act rashly, in ways that tend to be seen as risky, with a lack of forethought, and with focus on immediate rewards without regard for potentially negative future consequences (Lejuez et al., 2010, Patton et al., 1995, Rogers et al., 2004, Barratt, 1983, Dawe et al., 2004). As with sensation seeking, attempts to link impulsivity to risk taking reveals associations that are modestly predictive and appear mediated and moderated by a host of other factors (Begg et al., 2003, Bina et al., 2006, Dahlen and White, 2006, Johnson et al., 1998, Lonczak et al., 2007, Magid et al., 2007, Oltedal and Rundmo, 2006, Stoltenberg et al., 2008, Fernandes et al., Leshem and Glicksohn, 2007).

In non-clinical populations, both sensation seeking and impulsivity appear highly contextual, determined by the particular reward conditions and consequences associated with a specific risk taking behaviour (Levin et al., 2007, Vigil-Colet, 2007, Llewellyn, 2008, Skeel et al., 2007). Moreover, these characteristics, especially in males, tend to follow a predictable neurodevelopmental course (Cooper et al., 2003, Arnett, 1991, Begg and Langley, 2001, Bina et al., 2006, Deakin et al., 2004, Hatfield and Fernandes, 2009, Laurence, 2010, Steinberg, 2004, Steinberg, 2007, Keating and Halpern-Felsher, 2008). These factors are likely superimposed on HRD behaviour. For example, male gender and younger age are significantly correlated to HRD, and young males are over-represented in the HRD population. Their propensity for impulsive and sensation-seeking behaviour has been interpreted as indicating the underlying personality-based mechanisms of HRD. At the same time, the majority of young male drivers do not belong to the HRD population (Begg and Langley, 2004, Arnett, 1991, Arnett, 1992, Cavallo and Triggs, 1996). Of those that do, most do not suffer from personality or impulsivity disorders (Llewellyn, 2008) and do not engage consistently and enduringly in multiple HRD behaviours (Fernandes et al., 2010, Fernandes et al., 2007, Smart and Vassalo, 2005). Hence, the major challenge confronting the HRD research is not how to identify and intervene with a subgroup of drivers who possess a behavioural disorder, but resolution of a thornier question: what are the underlying explanatory pathways that motivate drivers from a non-clinical, heterogeneous population to repeatedly engage in some HRD behaviours and not others? Headway in resolving this problem would be the precursor for designing more focussed interventions that are capable of disrupting these pathways (Hoyle et al., 2000, Eby and Charles, 2004).

Recent developments in the closely aligned risk taking research are instructive in this regard. In contrast to the traditional psychometric paradigm described above, greater emphasis is now being placed upon the dynamic decision-making processes and neuropsychological functioning underlying risk taking (i.e., the neuropsychological paradigm) (Hoyle, 2000, Workgroup, 2000, Boyer, 2006, Steinberg, 2007, Llewellyn, 2008). This represents a shift away from reliance on self-report questionnaires that measure broad personality characteristics (Q-data in Cattell's (Cattell, 2007) terminology) towards the deployment of tasks that can elicit the individual biochemical, cognitive, affective and social processes underlying risk taking behaviours (i.e., T-data) (Bevins, 2001, Harrison et al., 2005, Skeel et al., 2007). Interestingly, when measuring the same construct (e.g., impulsivity),

the few studies that have collected both forms of data find only weak or non-existent relationships between the two. This suggests that Q- and T-data are tapping into distinct processes (Franken and Muris, 2005, Lejuez et al., 2010, Reynolds et al., 2006), leading authorities to call for studies that include both data sources for a more complete understanding of individual differences in the risk-taking (Harrison et al., 2005, Skeel et al., 2007, Reynolds et al., 2006, Lejuez et al., 2010). Finally, as risky behaviour is often contextual, experimentation needs to be conducted under the social, environmental and motivational conditions germane to those encountered in HRD. In this regard, simulation (i.e., of driving and other risk taking behaviour) is a useful tool, given its capacity for safely providing data on risk taking behaviour under experimentally controlled conditions (Ouimet et al., 2010b, Schwebel et al., 2006, White et al., 2008, Fisher et al., 2007).

Summary Conceptual and methodological shortcomings have hindered our understanding about precisely how, and to what degree, psychosocial and personality correlates of risky driving actually contribute to HRD behaviour. The research has not possessed the acuity to identify explanatory pathways needed to unravel the heterogeneity in the HRD population, or to explain precisely how broad personality constructs like sensation seeking and impulsivity produce HRD behaviour. Practically this hinders our ability to better detect HRD and formulate targeted intervention approaches. This proposal argues that to make headway, we need a shift away from the traditional psychometric paradigm to more integrative multidimensional research that can identify the biochemical, cognitive, affective, and social explanatory processes contributing to HRD behaviour.

HRD subgroups

Both Vézina (Vezina, 2001) and Axis 5 of this request for proposals called for research to identify HRD subgroups and their motivational underpinning to inform targeted interventions. This challenge is being tackled by investigators in substance abuse (Cloninger et al., 1988), gambling (Blaszczynski and Nower, 2002), and other risk taking fields (e.g., Harrison et al., 2005 for review). The example of psychiatric research into endophenotypes, which attempts to discern “clinically meaningful” subgroups within heterogeneous clinical populations, is instructive in this regard. The members of such subgroups share common explanatory pathways to their behaviour, distinct biomarkers and behavioural features, and selective treatment responsiveness (Hutchison, 2008/6/4, Hines et al., 2005). Clarification of subgroups anchored to a common explanatory pathway in HRD would inevitably require the integrative, multidimensional research approach noted above. Its promise, however, is to aid development of interventions specifically designed to disrupt these pathways as well as the capacity to target them at the appropriate subgroup. We have identified two putative explanatory pathways upon which meaningful HRD subgroups may be anchored.

Neurocognitive pathway Self-regulatory and decision-making anomalies appear at the heart of much persistent, dangerous, and self-destructive behaviour including substance abuse, unsafe sex practices, and pathological gambling (Gonzalez et al., 2005). Cognitive deficits seen in individuals who repeatedly engage in these behaviours despite severe negative consequences involve executive processes

associated with the prefrontal cortex area (PFC) that are vital for successful goal-directed behaviour (planning, initiation, anticipation of consequences of actions) and the ability to adjust behaviour based upon environmental feedback (decision-making, behavioural inhibition, risk/reward appraisal) (Bechara, 2003). Neural mediators, particularly involving executive function, seem key to better understanding individual risk in HRD as well.

Strands of preliminary evidence support the applicability of this neuropsychology paradigm to HRD. Groundbreaking research by our group (Ouimet et al., 2007) found that, in a community-recruited sample of DWI offenders with from two to eight convictions, approximately 70% exhibited functional impairment on at least one index of neurocognitive capacity. Poorer working memory and visuospatial abilities were both associated with greater frequency of past DWI offences. Executive functioning deficits seem particular important in males compared to females offenders, which may explain the greater risks for HRD associated with male sex (Brown et al., 2010b). In another study, we found that poorer response inhibition capacities differentiated DWI offenders who had failed to engage in a DWI remedial program following their conviction from those who had (Brown et al., 2008), consistent with other studies indicating the importance of cognitive functioning to successful treatment engagement and outcomes (Aharonovich et al., 2003/8/20, Crews et al., 2005, Teichner et al., 2002/9). Other investigators have found executive function deficits in individuals who drive with elevated BAC (Domingues et al., 2009), and that high BAC in drivers acutely impairs inhibitory capacities and interacts with impulsive and sensation-seeking tendencies (Fillmore et al., 2008, Fillmore et al., 2009, Burian et al., 2002). Clearly, the impact on central executive control processes of acute and chronic alcohol use in HRD cannot be overlooked.

Having established the obvious role of executive functioning in DWI behaviour, our focus has now shifted to a more precise neuroanatomical, cognitive framework, the Somatic Marker Framework (SMF) (Bechara, 2003), to explore whether dysfunctional decision making seen in drug addiction, problem gambling and other forms of risky health-threatening behaviour (Bechara, 2003, Bechara, 2005, Bechara and Van Der Linden, 2005, Xiao et al., 2010) operates in HRD as well. According to the SMF, decision making is the product of two separate, but interacting, neural systems: i) an impulsive, rapid response, amygdala-dependent process for emotionally signalling the immediate negative or positive consequences of an option; and ii) a reflective, longer-lasting, ventral medial prefrontal cortex (VMPFC) dependent system for emotionally signalling the future negative or positive prospects of an option (Bechara, 2005). The final decision is determined by the relative strengths of the emotional signals associated with immediate or future contingencies. Two types of dysfunction may lead to emotional signals that favour immediate positive outcomes despite greater unpleasant future consequences (i.e., impulsivity): i) hyperactivity in the amygdala (or impulsive) system, which exaggerates the value of an immediately available option/reward; and ii) hypo-activity in the VMPFC (or reflective) system, which makes salient the long-term consequences of a given action. Interestingly, in addition to clinical groups, impairments are regularly observed in high functioning adults and adolescents as well as in heavy drinkers who continue to function adequately, suggesting that under certain environmental conditions these individuals could develop future

problems (Bechara, 2003, Bechara, 2005, Johnson et al., 2008, Weller et al., 2009). The SMF seems relevant to HRD, where impulsive, short-term positive options appear to persistently outweigh longer-term negative consequences (e.g., in DWI, the convenience of driving to the bar versus the danger associated with later driving home when impaired; in risky driving, the thrill of taking risks versus the potential of an accident or driving citation).

The Iowa Gambling Task (IGT) was developed by co-applicant Bechara and colleagues (Bechara et al., 2005b, Wardle et al., 2010, Li et al., 2010) for evaluating decision-making capacities associated with VMPFC impairments (see Measures, Tasks and Questionnaires section below). In a study conducted by one of our team's graduate students (Maldonado et al., 2010), the IGT was used to compare performances between recidivists and normal drivers recruited from the community. The results indicated that recidivists repeatedly chose a disadvantageous strategy in which small immediate monetary rewards were preferred despite longer-term losses compared to normal drivers ($\eta^2$ = 0.11). Moreover, evidence based upon measurement of galvanic skin response for a distinct emotional arousal pattern measured in recidivists just prior to choosing cards from the "advantageous" decks provided additional provisional support for the SMF in flawed decision making. These findings extend previous preliminary work by Bechara and colleagues (Yechiam et al., 2008) and other investigators (Kasar et al., 2010b, Lev et al., 2008) who used the IGT in HRDs recruited from clinical and prison settings, but did not collect measures of emotional signalling. That our study discerned decision-making anomalies in a community recruited sample is also significant, as there is good reason to believe that, except for their risk taking, many if not most HRDs are otherwise functioning adequately (Vezina, 2001, Smart and Vassalo, 2005). In sum, these preliminary results indicate that decision-making anomalies may be a plausible affective-cognitive pathway to HRD similar to that seen in other problem behaviours.

Neurobiological pathway Several lines of evidence indicate that hormonal and neurotransmitter systems influence the genesis and maintenance of alcohol abuse as well as other impulsive, risk taking behaviour. The hypothalamic-pituitary-adrenal (HPA) axis is one such conduit. Activation of the HPA axis occurs after exposure to physiological stressors like cold and pain, but even more so in response to psychological stressors like acute anxiety- or fear-provoking experiences. In humans, the major hormones of the HPA axis are corticotropin releasing hormone (CRH), adrenal corticotropic hormone (ACTH), and cortisol. CRH is synthesized and released in the by neurons of the paraventricular nucleus. CRH is transported to the anterior pituitary and stimulates the release of ACTH, which in turn stimulates the synthesis and release of cortisol by the adrenal cortex (Gianoulakis et al., 2005). HPA-axis dysregulation is viewed as an epigenetic phenomenon that arises from sustained exposure to stress and hyperarousal (Adinoff et al., 1990/4, Inder et al., 1995/9). Importantly, HPA hyperactivity may contribute to increased alcohol intake by heightening experiences of anxiety and craving (Fahlke et al., 1995/1, Hansen et al., 1995/9, Lamblin and De, 1996/5, O'Malley et al., 2002/2, Prasad and Prasad, 1995/1, Stewart, 2000/3, Valdez et al., 2002/10) and increasing alcohol's reinforcing effects through cortisol's modulation of mesolimbic dopaminergic transmission (Fahlke et al., 1995/1). In turn, HPA-axis hyporeactivity, indicated by

reduced cortisol reactivity to stress, is a trait marker of risk taking involving lowered fear reactivity [129], arousal seeking, aggression, impulsivity, psychopathy and alcoholism (Kagan et al., 1988/4/8, O'Leary et al., 2007/2, Cima et al., 2008).

In light of some similarity between many of the behavioural correlates of HPA dysregulation and DWI, our research group explored whether HPA-axis activity could be a psychobiological marker of HRD as well. In a pilot study (Brown et al., 2005) we collected salivary cortisol, a readily available index of HPA-axis activity, from a sample of 104 male DWI offenders exposed to mild psychological stress. Among multiple DWI offenders ($n = 62$), a significant inverse relationship emerged between cortisol response to the stressful experimental conditions and past frequency of DWI convictions ($r = - 0.42$, $p < 0.005$). This relationship was more powerful than any of the self-reported psychosocial assessments of problem drinking and adjustment that were also administered and that are commonly used in clinical alcohol and DWI screening. Moreover, cortisol explained a significant proportion of the DWI variance independent of alcohol misuse. A follow-up study (Couture et al., 2008) by Couture et al., a Ph.D. candidate in our team, incorporated a non-DWI driver comparison group to confirm the robustness of these initial findings as well as their specificity to the DWI population. Shared variance between cortisol and experience-seeking on the SSS (Zuckerman and Kuhlman, 2000) was also uncovered, a finding previously observed in other risk-taking groups (e.g., college students). Initial analysis of data from on-going longitudinal research by our group (Couture et al., 2010) indicates that HPA-axis reactivity can differentiate between low and high-risk first-time DWI offenders ($d = 0.76$), supporting its sensitivity as a marker of recidivism risk in this extremely heterogeneous population (Nochajski and Stasiewicz, 2006).

A final set of findings leads us to hypothesize that HPA dysregulation is a putative pathway to non-DWI HRD. In collaboration with National Institutes of Health (NICHD) and Virginia Polytechnic Institute (Virginia Tech), we (Ouimet et al., 2014) collected data on cortisol reactivity to psychosocial stress from 41 novice drivers (mean age 16.3 years). The naturalistic vehicle operating behaviour of these young drivers was then prospectively assessed over an 18-month period using cameras, and motion and g-force sensors installed in their vehicles. Though hypothesized, but surprising nonetheless, we found strong relationships [$r(38) = -.51$, $p < 0.005$] between cortisol reactivity and crash and near-crash frequency. As alcohol was not a factor in these events, we hypothesize that blunted cortisol in young drivers demarcates two potential homeostatic processes in HRD: a) increased levels of arousal are sought through greater risk taking; and b) reduced arousal following fear and stress provoking experiences (e.g., dangerous driving situations or consequences) interferes in emotional memory processing involved in behavioural inhibition (Pruessner et al., 2007).

## Annexe 2: La methodologie

Site The Addiction Research Program (ARP) of the Douglas Hospital Research Center (DHRC) is McGill University–affiliated and the site of participant recruitment and experimentation.

Participant inclusion/exclusion criteria

Two main groups will be recruited: Normal drivers (n = 50) and HRDs (n = 100) for N = 150. Power calculations for sample size determination are presented in the Procedures section below. General inclusion: Males with a regular (non-probationary license) drivers licence aged 19 to 39 (due their over-representation in the HRD population, internal validity, the study's preliminary nature, and budgetary constraints against recruitment of male and female samples for bona fide sex and gender based analyses). Group HRD inclusion: Based upon Vézina's operationalization (Vezina, 2001), minimum of 3 distinct events within the previous 2-year period (i.e., road or criminal conviction, license suspension, reported crash, first DWI conviction with blood alcohol level (BAC)>150mg/100ml or involving refusal to provide breath sample, recidivism, driving with a suspended licence); Normal driver inclusion: not fulfilling above HRD criteria and no DWI conviction or more than one speeding citation in the last 5 years. General participant exclusion: Acute or chronic ill health precluding safe participation, BAC >.02, psychoactive substance use in past 48 hours and reading skills < 6$^{th}$ grade.

Recruitment strategies From previous work (Brown et al., 2010a, Brown et al., 2005, Couture et al., 2010), we have devised several ethics committee-approved protocols for recruitment. Advertisements are placed in local newspapers briefly describing the study, its inclusion criteria, and providing telephone coordinates to the project coordination team for interested individuals. We also can recruit via our website (http://www.douglas.qc.ca/study/dui-men-women), which works very well. If necessary, another strategy we have used successfully (e.g., Maldonado et al., 2010) is to access our database of DWI offenders that have participated in previous unrelated studies and who have provided us with consent to re-contact them for further participation in research. We will preselect individuals who are likely to fulfil inclusion criteria for this study (e.g., a recent DWI offense with BAC > 0.15 and other qualifying offences). Their current status and eligibility will be initially screened over the phone and recruitment will be completed at the scheduled test session.

Methodological notes 1) Recruitment feasibility: We have conducted five major funded studies in the HRD area and have reliably met our recruitment targets (i.e., in excess of 700 HRDs), even when trying to recruit hard-to-reach, treatment shy recidivists with substance abuse problems from the community (Brown et al., 2010a). Based upon this experience, key to recruitment success is flexibility and creativity in deploying multiple simultaneous recruitment strategies: intensive wide net capture methods (i.e., broad inclusion criteria in advertisements), frequent renewal of recruitment drives, flexible week and weekend scheduling, and adequate compensation ($160.00) for full day participation; 2) Group composition: We are seeking to recruit a representative heterogeneous HRD sample as opposed to "pure"

Speeders and DWI groups. Hence, a distribution is anticipated on two major HRD characteristics, namely greater or lesser involvement in speeding and DWI behaviours. Accordingly, for analyses of hypothesized group differences (i.e., $H_{1d}$, $H_{1e}$, $H_{2a}$), multivariate cluster analysis on high-risk behaviours will statistically discern a group of primarily Speeders and primarily DWI HRDs.

Participant screening and study induction When study candidates call the study research recruitment agent, they are provided information about the study, have their questions answered and if appropriate, asked inclusion/exclusion questions. If they meet inclusion criteria and agree, they are provided a rendezvous at the lab. At arrival at 8:30 AM, prospective participants are asked to present picture identification to validate identity, as well as proof of their drivers' license status. Pertinent documentation concerning HRD offenses is verified at that time. They are given Ethics approved Informed Consent forms to read, to question, and then sign if acceptable. They undergo a Breathalyzer® test and urinalysis to ensure that they are not presently under the influence of alcohol or drugs during the interview. In the event of BAC > 0.02 or a positive drug screen, the interview will be delayed or rescheduled. A cursory health screen is followed by a brief alcohol and drug screening (using MAST, DAST). If the research agent detects signs of medical risk, their inclusion is vetted by the team's physician/investigator (JT). Time for completion of study participant induction will be variable, but we estimate 15-20 minutes for the reading of the consent form, medical verification, and biological sampling.

Measures, tasks and questionnaires All questionnaires and tasks are available in validated Francophone and Anglophone versions, all except two have been employed in our past research. General sociodemographic information is collected via the instruments below. Data on vocational, legal and mental health status is collected using the Employment, Legal and Psychiatric sections of the Addiction Severity Index, which also provide an aggregate objective score for each section (15 min) (Brown et al., 1999, Daeppen et al., 1996).

Explanatory pathway measures (T-data)

Decision making Co-PI Bechara and colleagues (Bechara et al., 2005b, Wardle et al., 2010, Li et al., 2010) developed the Iowa Gambling Task (IGT) to detect decision-making anomalies associated with impairments in the VMPFC. Using the BIOPAC™ computerized Iowa Gambling Task, four decks (40 cards each) of cards (labeled A, B, C, and D) are presented on a computer screen. Participants are instructed to select cards from any deck to accumulate as much play money as possible within 100 trials. The total amount of money the individual accumulates is displayed. Play money earnings are converted to small monetary rewards to increase participant engagement and motivation in the task. Unbeknownst to the participant, the decks differ on the amount of potential gain versus the amount of potential losses. Decks A and B are set so penalties outweigh rewards, making these decks disadvantageous; decks C and D are programmed so gains outweigh penalties, making them advantageous. Optimal performance is achieved by avoiding decks A and B and selecting decks C and D. Performance is reported as a

net score calculated by subtracting the number of disadvantageous selections (decks A and B) from the number of advantageous selections (decks C and D). Skin conductance response is used to test the Somatic Marker Framework during performance the IGT. Ag-AgCl electrodes are placed on the distal phalanges of the non-dominant hand of the participant. BIOPAC's AcqKnowledge™ 4.11 program provides an automated and computerized method for collecting, extracting, and analyzing skin conductance response data along with IGT data. Skin conductance response in the five seconds prior to card draws reflects the emotional signalling in anticipation of outcomes from each card draw. The SMF posits a distinct emotional signalling patterning in individuals with impaired decision making (25-30 min).

Emotional arousal to stress Testing HPA-axis activity to stress involves sampling salivary cortisol, a biomarker of HPA-axis activity, to psychosocial stress. The protocol begins at exactly 11:30 AM to control for fluctuations due to circadian cycles. A standard lunch and scheduled smoking breaks (if necessary) are provided followed by a two hour interval prior to initiation of saliva sampling, since cortisol response is sensitive to these events (Gianoulakis et al., 2003). Basal salivary cortisol sampling begins at 13:30 and then reactivity is sampled at 15 minutes intervals for a total of 9 samples. Between saliva sampling, the participant rests. Exposure to the stress task follows collection of the third saliva sample and consists of a standardized mental arithmetic challenge under the pressure of time and rewards ($50, 40, 30, 20, 10 to the five highest scorers out of every 15 participants) (Gianoulakis et al., 2005, Couture et al., 2008). Salivary cortisol sampling is a non-invasive and stress-free technique using the Salivette® device (Sarstedt, St. Laurent, Quebec, Canada), a little gum-sized swab which participants chew for several seconds. Samples are frozen immediately until assayed. The content of cortisol in saliva is estimated using the AMERLEX® Cortisol radio-immunoassay kit (cat. # 8758401; Ortho-Clinical Diagnostics, Inc. Rochester New York) and reported as □g cortisol/ assay is 0.1 □g/100 ml, intra-assay and inter-assay variation coefficients are 4.3% and 7.7 % respectively. Two main measures are calculated: 1) basal (resting) cortisol, or the mean of cortisol levels gathered at the rest session for intervals 4 – 9; 2) during the stress task, total cortisol response (i.e., area under the curve [AUC]) from intervals 4 – 9, with each cortisol reading from intervals 4 - 9 being the increase or decrease in cortisol from mean basal cortisol level (Pruessner et al., 2003) (3.5 hours in total).

Other relevant dimensions of executive functioning Tests are selected in order to provide a broad but rapid appraisal of other general executive functioning dimensions. The Connor's Continuous Performance Test (CPT) is one of the most frequently used laboratory tasks in the clinical assessment of ADHD in adults and children. Participants monitor stimuli presented on a computer screen, responding only when they detect a predetermined letter (e.g., X) after seeing another predetermined letter (e.g., A). It can also detect problems in attention, impulsivity, and vigilance (Nichols and Waschbusch, 2004) (15 min). In the D-KEFS Color-Word Interference Test – Inhibition (Delis et al., 2001), participants are presented with color names (i.e., red, blue, or green) printed in different colored ink (i.e., red, blue, or green) and asked to name the color of the ink and not read the word itself. Time

(in seconds) taken to complete the task is used as the outcome measure, with studies associating longer delays with inhibition difficulties (Homack et al., 2005) (10 min).

Risk taking with simulation

Driving This study is conducted using driving simulation. Design and costs of this technology was subsidized by our CIHR team grant (SAF-195811). Our recent review of the simulation literature (Ouimet et al., 2010b) underscored: i) its advantage for research into mechanisms underlying drivers' risk, ii) its safety, convenience and low cost for observing regular driving performance, and iii) its amenability to experiments that infer causality. The generalizability of observations to real driving has been demonstrated in several studies (e.g., Schwebel et al., 2006). The simulator uses a motorless 2005 Smart® vehicle interacting with a computer-generated simulated roadway displayed on large 3-D screens located in front and on the sides of the vehicle. When the driver accelerates, turns, decelerates, goes up an incline, etc., the vehicle reacts to the driver's commands on the simulated road as it would on an actual road. Participants are exposed to two 15-minute driving sessions that provides common road challenges (e.g., left hand turns in traffic, passing and car following scenarios, daytime and night-time, restricted vision etc.). Each session contains an urban, suburban, and rural section. Participants drive one practice session and one experiment session. The simulator records mean speed, following distance, gap acceptance along with other driving parameters (e.g., crashes). Data are entered automatically into a digital database (45 min).

Risk propensity Balloon Analogue Risk Task (BART) (Lejuez et al., 2002) is a computerized laboratory-based measure of general risk taking propensity. It has been shown valid, generalizable and reliable in several clinical and non-clinical populations (Hunt et al., 2005, White et al., 2008). Participants ''pump up'' an on-screen balloon with the goal of making the balloon as large as possible without causing it to explode. Participants are given points for each pump if they decide to ''cash out'' before the balloon explodes. Each explosion results in a loss of points earned for that balloon. Individuals who engage in higher levels of risk demonstrate more pumps per balloon as well as more balloon explosions. The BART consists of 30 trials/balloons. The balloons have different explosion probabilities; however, the average explosion point is 64 pumps. The average number of pumps across all unexploded balloons is the most useful measure of performance (7-10 min).

Psychological and psychosocial characteristics (Q-data)

Personality The short version of the NEO Personality Inventory (Costa and McCrae, 2001), the NEO-FFI (McCrae and Costa, 2004) measures five broad domains of personality: neuroticism, extraversion, openness, agreeableness, and conscientiousness. Internal consistency and convergent and divergent validity have been demonstrated as adequate. (10-15 min). The UPPS-P Impulsive Behavior Scale, developed to clarify inconsistencies in the literature (e.g., Zimmermann, 2010, Magid and Colder, 2007), encompasses five facets of impulsivity including

negative and positive urgency (emotion-based impulsivity), lack of premeditation, lack of perseverance, and sensation seeking. Reliabilities of its scales range from 0.051 to 0.90 and its factor structure has been found to be robust (Whiteside and Lynam, 2001) (10 min).

Intelligence The Wechsler Abbreviated Scale of Intelligence (Ryan et al., 2003) is a screening instrument that provides an estimation of general intellectual functioning for research purposes. Composed of four subtests, two verbal and two performance, it has been correlated with neurocognitive functioning (Berger, 1998), and may be used to account for potential group differences (30 min).

Substance use The Timeline Follow Back has been recommended as an "optimal" measure for alcohol and drug abuse studies (Hoeppner et al., 2010). It presents participants with a calendar to aid recall of daily drinking and drug use over the past 90 days (10 min). A Breathalyzer® test will be used to objectively detect recent alcohol use and determine BAC at time of testing, and urine specimens will be obtained for urinalysis detection of recent cannabis, cocaine and benzodiazepine use, the most commonly abused drugs we have detected in DWI offenders (Brown et al., 2005). The Michigan Alcoholism Screening Test (MAST) is a clinical 10 item screening instrument providing an index of alcohol problem severity and related negative consequences with adequate parametric qualities in HRD samples (Conley, 2001) (<5 min). The Drug Abuse Screening Test (DAST (Skinner, 1982) is brief self-administrated questionnaire and yields a quantitative validated index of drug problem severity (<5 min) (Yudko et al., 2007). The TLFB, BAC, urinalysis, MAST and DAST will be used for medical screening, sample description, and exclusion decision making.

Self-reported risky driving The Manchester Driving Behaviour Questionnaire (DBQ) (Reason et al., 1990) is widely used in traffic safety research and consists of 24 items that measures two main hypothesized human sources of accidents, error and violations. It has been translated into several languages and culturally validated in several countries and contexts (Lajunen et al., 2004, Verschuur and Hurts, 2008) with adequate reliability and consistency in factor structure (< 5 min). With the aid of the TLFB method above, participants will also be queried on the kilometres driven in the past 12 months, as well as the number of times they engaged in drink-driving, defined as ≥ 3 standard drinks in the two hours (< 5 min).

Procedures The first component of the assessment goes from at 8:30 AM to 11:30 with Informed consent, health and drug screening, the psychological and psychosocial assessment, other executive functioning tasks and the BART, with strategically scheduled rest breaks. Then, the cortisol protocol proceeds until 3:00 PM. Finally, participants are administered the IGT and driving simulation task to finish at 4:15 PM.

Methodological notes: Our past studies and current protocols indicate good tolerance and engagement in general to such day-long testing sessions, even in older participants than the young cohort recruited here. Regular rest and snack breaks, a propitious mix of tasks and demands to avoid boredom, monetary

incentives for performance, and the flexibility to reschedule in the rare case where the participant is significantly slower in completing some tasks or overly fatigued are essential. We typically pilot test the entire protocol on 5 individuals to further refine the final schedule, and will do the same here.

Main statistical analysis plan and sample size considerations

$H_{1a}$: HRDs exhibit decision-making processes that favours immediate gains over later losses compared to normal drivers Analysis overview: Repeated measures ANOVA, with if necessary intelligence score (WASI) as covariate (in repeated measures ANCOVA). Dependent variable (DV); IGT scores. Independent variables: Between factor-Group (1.HRD, 2. Normal drivers); Within factor-Blocks (5). Power calculation: Repeated measures ANOVA from our study (Maldonado et al., 2010) comparing IGT scores between DWI recidivists and normal drivers revealed a significant group effect with a partial $\eta^2 = 0.11$. ANOVA comparing repeated traffic offenders and normal drivers by Lev and colleagues (Lev et al., 2008) revealed an effect size Cohen's d = 0.64 (i.e., $\eta^2 = 0.09$). For Bonferroni correction of alpha for multiple comparisons, we set two-tailed $p \leq 0.0125$ for $H_{1A}$ and $H_{1B}$. Using Systat© v.13, inputting $p \leq 0.0125$ for inferences, power at 0.8, means of 5 blocks of 20 card draws each, and 2 groups, we would require from N = 58 to 72 (total), well within our recruitment targets.

$H_{1b}$: HRDs exhibit dampened arousal to stress compared to normal drivers. Analysis overview: Independent sample T-tests. DV: Salivary cortisol (Area under the curve – basal); IV: Group (1.HRD, 2. Normal drivers). Power calculation: Using statistics from our study (Ouimet et al., 2010a), comparisons on cortisol between risky young drivers (crashes or near crashes $\geq 5$) and low risk drivers yielded an effect size of Cohen's d = 0.67. In another laboratory study (Couture et al., 2010), we compared cortisol of first time DWI offenders versus controls and found an effect size of Cohen's d = 0.76. Inputting $p \leq 0.0125$ for inferences, power at 0.8, we would require N = 82 to 104, well within our recruitment targets.

Methodological note: We purposefully recruit a representative heterogeneous sample of HRDs rather artificially "pure" samples of speeders or DWIs. Hence, we assume a distribution of greater or lesser speeding and DWI behaviours as opposed to "pure" speed-HRD and DWI-HRD groups. Accordingly, prior to testing $H_{1C}$ and $H_{1D}$ below, we will use multivariate cluster analysis on high-risk behavioural measures (i.e., DBQ, MAST, DAST, days of drink driving derived from the TLFB, and frequency and type of driving citations received over the past 2 years) to statistically derive primarily speeding (Speeders) and primarily drinking driving (DWIs) subgroups.

$H_{1c}$: DWIs show more impaired decision-making than Speeders and Normal drivers Analysis overview: Planned comparisons: 1) DWIs vs. Normals; 2) DWIs vs. Speeders. Dependent variable: DV: Iowa Gambling Task scores.

$H_{1d}$: Speeders show lower arousal to stress compared to DWIs and Normals

Analysis overview: Dependent variable: DV: Salivary cortisol (Area under the curve – basal). Planned comparisons: 1) Speeders vs. Normals; 2) Speeders vs. DWIs. Power calculation: As we conduct two orthogonal planned comparisons, no further correction of alpha is required. Hence, for both $H_{1C}$ and $H_{1D}$, we use the input parameters for power used in $H_{1b}$ to arrive at the same sample size estimates.

$H_{2a}$: HRDs exhibiting decision-making that favours immediate gains over later losses show greater risk taking behaviour compared to either HRDs who do not or Normal drivers. Analysis overview: A median split of HRDs on the IGT to determine impaired versus unimpaired decision-makers. Then, one-way MANOVA. IV: Three groups – group 1) Impaired decision-makers among HRDs; group 2) Unimpaired decision-makers among HRDs; group 3) Normal drivers. DVs: Risky Behaviour – risky driving simulation (mean speed, following distance, and gap acceptance); risk propensity (BART); and self reported risking driving (DBQ).

$H_{2b}$: HRDs exhibiting reduced arousal to stress show greater risk taking behaviour compared to either HRDs who do not or Normal drivers. Analysis overview: A median split of HRDs on salivary cortisol response to stress to determine high responders versus low responders. Then, one-way MANOVA. IV: Groups- 1) High cortisol responders among HRDs; 2) Low cortisol responders among HRDs; 3) Normal drivers. DV: Risky behaviours – Risky Driving simulation (mean speed, following distance, and gap acceptance); risk propensity (BART); and self reported risking driving (DBQ). Power considerations for both $H_{2a}$ and $H_{2b}$: With a sample size of 150, power at 0.80, 3 groups, 5 predictor variables, these analyses will be powered to detect an effect size in the low medium range (Cohen's d = 0.45-0.50), which is well below the range of effect sizes we and others (noted above) have found in related work.

Hypothesis generating exploratory analyses: The relative strength of relationships between DVs - Risky driving simulation (mean speed, following distance, and gap acceptance); risk propensity (BART); and self reported risking driving (DBQ), with IVs - salivary cortisol, IGT scores, CPT and D-KEFS Color Word Interference Test, IQ, age, psychosocial functioning (ASI scores on Legal and Employment sections), dimensions of personality (UPPS, NEO-FFI) and HRD status (Normal driver [0], DWI [1], Speeder, [2]) will be investigated using canonical correlation. Though a relatively limited empirical statistical approach, it does permit exploration of the relative orthogonal linear contribution to the risk taking variance by different individual dimensions (i.e., psychosocial, personality, cognitive and neurobiological) (Tabachnick and Fidell, 2007). Use of other exploratory non-linear techniques will be considered depending on our initial findings. Power considerations Assuming reliability of variables to be about 0.80 (typical of social science variables), then 10 cases for each variable is acceptable (Tabachnick and Fidell, 2007). We expect better reliability in T-data variables. Nevertheless, this conservative assumption permits up to 15 variables in this analysis. Initial inspection of correlation matrices, and possible deployment of Principal Components Analysis could help to reduce the number of variables in order to ensure the power and stability of this analysis.

Project timeline We anticipate recruiting 3 participants per week, based upon past experience (no shows, re-scheduling a second day in rare instances) and our physical resources (e.g., interview room availability). Hence, with the need to oversample by 10% (i.e., N = 165), we will require approximately 55 weeks for data collection. With 46 complete working weeks/year, this represents approximately 14 months for data gathering. With a one-month start up and pilot phase, and one month downstream for final data processing and database finalization, the active budget phase of the study will terminate at 18 months. On-going budget-independent data analyses by the PIs and their students will likely go beyond the formal project duration, but we anticipate preliminary findings based upon testing our main hypotheses to be available for presentation to FRSQ-FQRSC-SAAQ and other stakeholders between months 20- 21. Of course, wider dissemination will occur in the months and possibly even year following formal project termination.

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