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RESEARCH REPORT

Application of Technological Advances in the Assessment and Treatment of Addiction in Corrections: A Systematic Review

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Application of Technological Advances in the Assessment and Treatment of Addiction in Corrections: A Systematic Review

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Executive Summary

Key words: *impulse control, addictive disorders, substance use, offenders, technology*

Substance use disorders are highly prevalent among offenders in the criminal justice system, with estimates as high as 70-80% in Canada. This report summarizes innovative applications of technology to assess and treat addictive disorders among offenders in the criminal justice system, with a focus on impulse control deficits. Impulse control is a multi-faceted construct that includes the ability to inhibit inappropriate responses, to delay gratification, and to avoid making risky choices. A wealth of validated computerized measures of impulsive behaviour have been employed in research with offenders. This report addressed three goals: (1) conduct a systematic review of research using technology to assess impulse control in offenders; (2) summarize current knowledge about the neural basis of these deficits; and (3) discuss innovative applications of technology to treat addictive disorders, with a focus on application in correctional settings. Based on the results of this review the following conclusions are offered:

- The systematic review included 28 peer-reviewed studies in offenders in two cognitive domains (inhibition and risky/impulsive decision-making). Across the studies, offenders showed relatively consistent deficits in response inhibition and delay of gratification (e.g., impulsive choices). Findings for risk-taking measures were less consistent, with some studies reporting excessive risk orientation and others not.
- Research using structural and functional neuroimaging has consistently implicated deficits in the frontal lobes (e.g., prefrontal cortex) as a correlate of impulse control deficits in offenders. This includes structural deficits in brain volume, decreased functional brain activity during task performance, and disruption in timing and amplitude of brain responses during response inhibition.
- Several behavioural and neuroimaging studies suggested that impairments in impulse control and corresponding brain deficits may serve as a risk marker for future criminal involvement and reoffending.
- Recent technological innovations have led to the development of novel interventions for addictive disorders that have shown initial efficacy in correctional settings. These include mobile/smartphone, internet, and virtual reality-based interventions. These modalities may be especially advantageous in prison settings due to significant barriers to consistent access to evidence-based “best practice” treatments this environment. However, research in this area remains limited.
- Research on the interaction of impulse control deficits, criminal behaviour, and substance use disorders is critically lacking. An important priority for research is to study impulse control deficits among offenders with histories of problematic levels of substance use.

In summary, the extant research supports the hypothesis that offenders exhibit significant difficulty in controlling their behaviour on technology-based assessment of impulse control. The patterns of behavioural performance and neuroimaging results are consistent with findings in substance use disorders, but the lack of research on offenders with addictions precludes definitive conclusions about this overlap. Given the role of impulse control problems in addictive disorders and criminal behaviour, further research to understand the interaction of these factors would increase knowledge and benefit planning for the management of individuals involved in the criminal justice system.

Table of Contents

Acknowledgements ii
Executive Summary iii
List of Appendices v
Introduction 1
Part 1: Systematic Review of Technology-Based Assessment of Impulse Control and Decision-Making in Offenders 6
Method 6
Results 11
Discussion 14
Part 2: Neuroimaging Approaches to Examining Neural Correlates of Impulse Control in Offenders 17
Part 3: Novel Technology-Based Treatment for Addictive Disorders 23
General Discussion and Conclusions 27
References 29

List of Appendices

Appendix A 43
Appendix B 44

Introduction

Deficits in impulse control have been shown to be contributing factors to both substance use disorders and criminal behaviour, and have important implications in determining risk of offending and recidivism. This section provides a brief introduction to the scope of substance use disorders among offenders, the role of impulse control deficits in addictive disorders, and the interaction of these factors in relation to offending.

High Rates of Substance Use Disorders among Offenders

Substance use disorders (SUDs) are highly prevalent in correctional systems. A recent meta-analysis of 24 studies with a total of 18,388 prisoners across 10 countries found that the pooled prevalence estimate of alcohol use disorder was 24% (Fazel, Yoon, & Hayes, 2017). Overall prevalence of drug use disorder (e.g., cocaine dependence, heroin dependence, etc.) was comparable to the alcohol estimates, but rates of drug use disorders in female prisoners were significantly higher compared to males (Fazel et al., 2017). In Canada specifically, data from Correctional Service of Canada reports indicate high rates among male and female offenders. For men, almost 70% of offenders had a substance use issue, with 37% in the moderate-to-severe range (Kelly & Farrell MacDonald, 2015b). Rates among women offenders were slightly higher, with between 77-80% having a substance use issue and 55% in the moderate-to-severe range (Farrell MacDonald, 2014a). Another Canadian report examining gender differences in use of specific substances indicated that the rates of alcohol use disorder were comparable between men and women, but women were more likely to have problems with drugs or both alcohol and drugs (Kelly & Farrell MacDonald, 2015a).

Variability in SUD severity in offender populations has important implications for length and intensity of treatment, the specific treatment modality chosen, and longer-term post-treatment needs. Increased severity of substance use problems is associated with reduced likelihood of being granted discretionary release (Farrell MacDonald, 2014b). More importantly, severity of SUD is a major contributing factor to the re-admission of offenders back into custody following release, with research indicating that as high as 70% of offender release suspensions involve alcohol or drugs (Farrell MacDonald, 2014b; Weekes, Millson, Porporino, & Robinson, 1994). In addition, among readmitted offenders, individuals without a SUD remained in the community nearly a month longer than those with severe SUDs (Farrell MacDonald, 2014b). Finally, a recent CSC report examining predictors of return to custody indicated a significant interaction between gender and severity of SUD. At low SUD severity, men were substantially more likely to return to custody relative to females, but this gap disappeared as severity of SUD increased (Biro & Farrell MacDonald, 2015). Collectively, these disorders pose unique challenges for institutions, particularly in terms of providing adequate screening and treatment, understanding factors that contribute to relapse, and the role of substance abuse in reoffending.

Despite the high prevalence of SUD, the psychological and neurobiological mechanisms that contribute to the development of addictions in corrections populations are not well understood. In a report on substance abuse in corrections, the Canadian Centre on Substance Use and Addiction emphasized the need for efficacious and "best practice" assessments and treatments that are well-founded in theory and based on empirical data (Canadian Centre on Substance Abuse, 2004). This report argued that interventions should target "criminogenic" factors that are predictive of criminal behaviour.

In recent years, there have been numerous technological advances in the assessment and treatment of addictive disorders with a focus on understanding the role of one potential criminogenic factor: deficits in impulse control. These advances include the development of neurocognitive tasks to characterize maladaptive decision-making (e.g., impulsivity, risk taking, inhibitory control); the application of neuroimaging techniques (e.g., functional magnetic resonance imaging, electroencephalography); and the development of internet and smartphone-based interventions for addictions.

Poor Impulse Control is a Core Feature of Addictive Disorders

Several decades of empirical research has found consistent evidence of impulse control deficits in individuals with addictive disorders (de Wit, 2009; Perry & Carroll, 2008). Impulse control is a multi-faceted construct that is can be captured via behavioural tests measuring the domains of inhibitory control, risk taking, and delay of gratification. In the first domain, people with SUD show pronounced deficits in the ability to inhibit or suppress inappropriate responses on laboratory response inhibition tasks (e.g., Fillmore, 2003)). These deficits are thought to play a key role in loss of control over one's drug and alcohol use as well as contributing to poor decisions made while under the influence of these substances. In the second domain, a greater propensity to engage in risky behaviour is commonly observed in addiction (Bornovalova, Daughters, Hernandez, Richards, & Lejuez, 2005; Dahne, Richards, Ernst, MacPherson, & Lejuez, 2013). This includes taking physical risks while intoxicated, such as driving a vehicle or engaging in other risky activities (e.g., swimming, climbing, etc.). Finally, difficulty in delaying gratification in favour of immediate rewards has been argued to be a central process in addiction (Warren K Bickel, Johnson, Koffarnus, MacKillop, & Murphy, 2014). For example, two meta-analyses have indicated that people with addictive disorders are significantly more likely to prefer smaller-immediate rewards over larger-delayed rewards on measures of delayed reward discounting (Michael Amlung, Vedelago, Acker, Balodis, & MacKillop, 2016; James MacKillop et al., 2011). Collectively, these deficits have important implications for the initial development of addictive disorders, severity of disorder, and response to addiction treatment.

Impulse Control Deficits and Substance Misuse Contribute Substantially to Criminal Behaviour.

Use and misuse of alcohol and other drugs is strongly associated with criminal activity (e.g., violence, property offences, etc.). CSC data on federal offenders indicate that alcohol or drugs were a major contributing factor in a range of offences, including driving under the influence, assault, theft, murder, and robbery/breaking and entering (Brochu et al., 2002). For example, nearly half (47%) of women offenders, criminal offending was related to substance use (Farrell MacDonald, 2014a). In another study, severity of substance use was related to the probability of committing a violent offence and being a previous offender (Farrell MacDonald, Gobeil, Biro, Ritchie, & Curno, 2015). Combined use of alcohol and drugs was associated with even greater risk of violent crime and disciplinary offences.

A relatively extensive literature has linked self-control and impulse control deficits with criminal offending (e.g., (Longshore, 1998; Moffitt et al., 2011)). In the case of inhibitory control, criminal behaviour is associated with difficulty inhibiting inappropriate responses (C.-Y. Chen, Tien, Juan, Tzeng, & Hung, 2005; C. Y. Chen, Muggleton, Juan, Tzeng, & Hung, 2008). In the laboratory, this is evident by offenders having difficulty stopping themselves from responding to targets or other cues that signal that they should withhold a response. These measures often also include an element of competition between multiple responses (e.g., an automatic response that must be suppressed in favour of a non-automatic behavioural response). This is relevant to corrections because offenders often must make choices between engaging in one or more different behaviours. Some of these behaviours may be more reflexive or automatic but also associated with negative outcomes (e.g., the impulse to react with violence following a confrontation). If offenders have underlying deficits in their ability to inhibit their behaviour (poor impulse control), they may be more likely to engage in disruptive behaviour that contributes to initial arrest, disciplinary problems while in custody, and re-arrest following release.

For delay discounting, the fundamental principle being examined is whether individuals are able to resist temptation to seek immediate rewards in favour of larger rewards that are delayed in time. From the standpoint of offenders, this has clear relevance to maintaining long-term patterns of non-criminal behaviour and avoiding re-arrest. As one example, an offender on discretionary release may be enrolled in a community re-integration program or other educational / work program that is designed to increase long-term stability and reduce risk of re-arrest. The positive outcomes of these programs are often delayed in time and must be weighed against immediate (and perhaps even more appealing) alternatives such as substance use or other criminal behaviour. Individuals who are less able to delay gratification and focus on the delayed rewards may be at greater risk of poor outcomes from these types of programs. Not surprisingly, prior research has found that offenders exhibit problems delaying gratification on delay discounting tasks (Åkerlund, Golsteyn, Grönqvist, & Lindahl, 2016; A. Carroll et al., 2017; C. A. Lee, Derefinko, Milich, Lynam, & DeWall, 2017; Mishra & Lalumière, 2017). In addition, steeper devaluing of delayed rewards significantly predicts future engagement in criminal behaviour even after controlling for several other known risk factors (C. A. Lee et al., 2017).

In addition to examining behavioural performance deficits among offenders, it is also important to investigate how these deficits are related to differences in brain structure and function. A growing body of research using neuroimaging indicates that offenders exhibit significant deficiencies in regions of the frontal lobes, particularly in the prefrontal cortex. For example, two recent systematic reviews of neuroimaging studies revealed that the areas associated with aggressive or violent behaviors among offenders, particularly those characterized as impulsive, were largely localized in the prefrontal cortex (Bufkin & Luttrell, 2005; Yang & Raine, 2009). Differences in the structure and function of the prefrontal cortex between offenders and non-offender controls are consistent with neuroimaging studies in addiction that suggest that impulse control deficits in people with SUD are attributed, in part, to reduced neural activation or decreased volume of prefrontal regions (Crews & Boettiger, 2009; Mann et al., 2001; Sullivan & Pfefferbaum, 2005).

Purpose and Goals

The purpose of this report is to review the research literature on technological advances in the field of addictions with an emphasis on impulse control deficits and their implications for correctional settings. A secondary purpose is to review recent developments in the use of technology-based addictions interventions (e.g., computer / online-based treatments, tele-health) which may be promising complements to existing addictions treatment programs in corrections. The extant literature currently lacks a critical appraisal of applications of technology to understanding the role of impulse control deficits among offenders and its potential contributions to SUD in this population. To address this gap, the current literature review has three goals:

1) Conduct a systematic review of technology-based assessments of impulse control and maladaptive decision-making in offenders.
2) Describe how neuroimaging techniques can be employed to characterize the neural correlates of impulse control deficits in offenders.
3) Discuss technological advances in the treatment of addictive disorders, including internet/mobile and virtual reality interventions, and their applicability to corrections.

In addressing these goals, this report will provide a critical review of the extant empirical literature on impulse control deficits in offenders, what is known about the neural basis of these deficits, and novel technology-based addiction treatments that have potential to improve impulse control in this population.

Part 1: Systematic Review of Technology-Based Assessment of Impulse Control and Decision-Making in Offenders

This section presents a systematic review of the literature using computerized neurocognitive tasks to assess impulse control among offenders. Our review focuses on technology-based assessments of impulsivity, inhibitory control, decision-making, and risk-taking. Deficits in each of these domains have been consistently linked to addictive disorders, and are implicated in criminal behaviour and risk of recidivism. A secondary goal of the review was to reveal areas of limited research that represent promising targets for future study.

Method

Systematic Review Search Strategy and Study Selection

Studies were identified via searches of PubMed and MEDLINE databases using the following Boolean search terms: (Inhibit* OR Impulsivity OR Discounting OR "Stop signal" OR "No Go" OR Card OR Balloon OR "Iowa gambling") AND (Inmate* OR Incarcerat* OR Prison* OR Sentenced OR Detainee* OR Felon* OR Remand OR Criminal*). The task-related keywords were selected to capture general terms (e.g., inhibition, impulsivity) as well as specific neurocognitive measures (e.g., delay discounting task, stop signal task, Iowa gambling task; see task descriptions below). The corrections-related keywords were selected based on search terms used in previous systematic reviews in this population (e.g., (Fazel et al., 2017)). For inclusion, studies had to meet the following criteria: (i) published in a peer-reviewed journal between January 1, 1997 and December 31, 2017; (ii) written in English; (iii) inclusion of a sample of offenders; and (iv) inclusion of a technology-based assessment of impulse control. Limiting publications to the last 20 years allowed us to focus on relatively recent technological advances.

Study selection was implemented using the Covidence online systematic review platform (Veritas Health Innovation, Ltd). The selection procedure is depicted in Figure 1 and followed Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) standards (Stewart et al., 2015). First, titles and abstracts were screened for relevance and adherence to the above eligibility criteria. The remaining studies were subjected to full-text review by the first-author. Final decision on inclusion was made by consensus of the first and second authors.

Technological Measures of Impulse Control

This literature review focused on technology-based assessments of impulse control. Computerized tests of impulse control are advantageous for several reasons. From a practical standpoint, completing computerized tasks may be more engaging and stimulating for offenders than filling out a packet of questionnaires. This could yield increased interest and effort on the tasks. On balance, computerized tasks also allow the researchers to probe for low effort based on behavioural performance (e.g., missed responses, excessively slow response times). Computerized tasks also measure behavioural performance directly and are not reliant on self-report. Therefore, computerized measures may be more objective compared to self-report scales assessing impulsive characteristics. Performance-based tasks also may be less susceptible to demand characteristics compared to self-report measures (i.e., individuals are less able to provide misleading or false information based on their beliefs concerning the measure's purpose or the experimenter's goal in conducting the assessment). Finally, computerized measures can be relatively easily customized based on specific situations and demands. For instance, some tasks can be administered using mobile technology (e.g., tablets) or even via the Internet. Tasks also often involve responding to simple visual stimuli that are not contingent on reading ability.

Computerized assessments of impulse control that have been used in the context of corrections can be categorized into two broad domains. Domain 1 included tasks measuring response inhibition. Domain 2 included tasks measuring impulsive decision-making and risk-taking. Representative tasks and measures in each domain are briefly described below.

Domain 1: Response Inhibition. Response inhibition is a fundamental component of impulsivity that refers to the ability to inhibit inappropriate responses to external stimuli (Diamond, 2013; Wilbertz et al., 2014). Theoretical models argue that successful inhibition involves three inter-related processes (Barkley, 1997): (1) inhibition of the initial prepotent or automatic response to an event; (2) stopping of an ongoing response which permits a delay in decision to respond; and (3) preventing competing events and responses from interfering with self-directed responses (i.e., interference control). Several behavioural tasks have been developed to measure response inhibition, including the Go/No-Go paradigm, Stop-Signal Task, interference control tasks (e.g., Stroop, Flanker), and Continuous Performance Test.

Go/No-Go Task: In a typical Go/No-Go paradigm (e.g., (Kamarajan et al., 2005; Simmonds, Pekar, & Mostofsky, 2008)), participants are presented with a stimulus that indicates they should respond (a "go" stimulus) and a stimulus that indicates they should withhold their response (a "no-go" stimulus). Participants are told that during each trial they will be presented with one of these stimuli and their task is to either respond to the go stimulus by pressing a button as quickly as possible, or inhibit their response to the no-go stimulus. For example, participants are told that they must respond quickly when the letter 'X' is presented onscreen and not respond when the letter 'K' is presented. Performance on this task is measured by the number of responses made to a no-go stimulus (i.e., commission errors) and the number of times a response is not made to a go stimulus (i.e., omission errors).

Stop-Signal Task: The Stop-Signal Tasks (SST (Logan, 1994; Verbruggen & Logan, 2008)) involves quickly responding to a go-signal and withholding that response when presented with a stop-signal shortly after the go-signal is presented. For example, participants are told to press a button when a circle appears on the screen; however, on a small proportion of trials the circle is followed by a noise which indicates they should inhibit their response. The time delay in the presentation of the noise varies such that on some trials the delay is very short and stopping the response is relatively easy, and on other trials the delay is longer and suppressing the response is more difficult. Performance on this task is measured by the speed of responding to go signals, and the probability of suppressing the response or the time needed to suppress the response (stop-signal reaction time).

Continuous Performance Test: The continuous performance test (CPT; (Connors & MHS Staff, 2000)) is a relatively lengthy task that requires a participant to exert sustained attention in order to inhibit a response to infrequent target stimuli. Participants are asked to respond to a target stimulus (e.g., X) when it is preceded by a specified pre-target stimulus (e.g., A). Thus, participants respond only when presented with A-X in succession. Similar to the Go/No-Go task, performance on these tasks is measured by omission errors (i.e., target stimuli missed) and commission errors (i.e., responses to non-target stimuli).

Stroop and Flanker Tasks (Interference Control): Interference control tasks measure response inhibition by asking the participant to respond to a target stimulus while simultaneously being presented with irrelevant stimuli that must be disregarded. Two classic interference control tasks are the Stroop Color-Word task (Faunce & Job, 2000; Stroop, 1935) and the Flanker task (Eriksen, 1995). In the Stroop task, colour names are presented in either a congruent ink colour or an incongruent ink colour, and participants must respond by indicating the ink colour while disregarding the actual word presented. The flanker task requires participants to respond to a central target stimulus (e.g., an arrow) by indicating the direction in which the stimulus is pointed. On some trials, the central target stimulus is flanked by identical stimuli (e.g., > > > > >), and on other trials it is flanked by stimuli pointed in the opposite direction (e.g., < < > < <). On both tasks, performance is measured by percent of correct responses as well as an interference cost in reaction time (i.e., difference in average reaction time between congruent and incongruent trials).

Domain 2: Impulsive Decision-making and Risk-taking. Another type of impulse control deficit commonly exhibited by individuals in the correctional system is impaired decision-making and increased risk-taking behaviour. In the first case, poor decisions are often characterized by a high degree of impulsivity, or making choices that are short-sighted, poorly conceived, or lacking in adequate consideration of consequences. In the second case, increased risk-taking commonly manifests as engaging in unsafe behaviours or making choices that have an increased probability of negative outcomes. Tasks in this domain include delay and probability discounting tasks and computerized gambling decision-making tasks such as the Iowa Gambling Task. Importantly, these measures tend to be uncorrelated with the response inhibition measures reviewed above (James MacKillop et al., 2016).

Delay & Probability Discounting. Delay discounting tasks (Stein & Madden, 2013) require participants to make choices between smaller-sooner and larger-later rewards. Monetary rewards are most common (e.g., “Would you rather have $40 today or $100 in one month?”), but alternative versions of these tasks have been developed for other rewards (e.g., drugs of abuse, food, health outcomes). Regardless of the reward used, these measures involve systematically varying the magnitude of the immediate reward and delay to estimate indifference points corresponding to equal preference for immediate and delayed alternatives. Similarly, probability discounting tasks require participants to make choices between a smaller-certain reward and a larger-uncertain reward (e.g., “Would you rather have $25 for sure or $100 with a 50% chance?”). The size of the certain reward and the probability are systematically varied across trials to estimate the participant's indifference point corresponding to equal preference for certain and probabilistic rewards. On both tasks, the primary outcome measure is the rate of delay or probability discounting (denoted as *k* or *h*, respectively) that reflects the rate at which rewards lose their value as a function of delay or probability.

Gambling Tasks. The Iowa Gambling Task (IGT (Bechara, Damasio, Damasio, & Anderson, 1994)) presents participants with four virtual decks of cards and instructs participants to select one card at a time in order to maximize monetary gains and minimize losses. Two of the decks result in large gains (e.g., win $250) or large losses (e.g., lose $250), and two decks results in small gains (e.g., win $50) or small losses (e.g., lose $50). Advantageous task performance requires that participants forego potential large immediate rewards for smaller longer-term rewards in order to avoid larger losses. Another gambling task is the Cambridge Gamble Task (Rogers et al., 1999), in which participants make a series of choices between two response categories that vary in probability of winning. Specifically, the participant is presented with ten red and blue boxes in different ratios across trials (e.g., 50:50 or 75:25 red:blue). One box will contain a yellow token and participants are asked to bet points on the colour of the box in which they believe the token is hidden.

Common technology-based assessments of impulse control can be grouped into two domains, including tasks that assess inhibitory control (Domain 1) and tasks that assess impulsive decision-making and risk-taking (Domain 2). There are a number of extensively validated, computerized assessments in each domain have been used widely in addiction and corrections research.

Results

Sample Characteristics

The literature search yielded 1117 unique records after removal of duplicates, of which 1006 were deemed irrelevant based on title and abstract review. The remaining 111 articles were subjected to a full-text review, and 81 were excluded (see reasons for exclusion in Figure 1). A total of 28 studies were included in the final literature review. Included studies in each domain are summarized in Tables B1 and B2 in Appendix B. Eighteen studies examined measures in Domain 1; 10 studies examined measures in Domain 2. The geographic distribution of the studies was notable—44% of primary studies were conducted in North America (Canada and the USA), 33% in Europe, and 12% elsewhere. In terms of research setting, the majority (83%) of studies involved testing offenders inside a correctional institution or forensic hospital environment, with a smaller percentage of studies collecting data in research laboratories outside of institutions. Three studies examined juvenile offenders, with the remaining studies focusing on adult samples. Studies focusing on a specific type of offense (e.g., comparisons of violent and non-violent offenders) or a psychiatric group (e.g., offenders with psychopathy or antisocial personality disorder (ASPD) were also relatively common. Antisocial personality disorder is defined as a psychiatric syndrome reflecting persistent disregard for laws, rules, and norms, often resulting in criminal behavior. In addition, ASPD is associated with substantial adverse interpersonal behavior such as lying, manipulation, hostility, aggression, and lack of empathy

Findings with Inhibitory Control Measures (Domain 1)

A majority of the included studies in Domain 1 reported increased inhibitory errors in offenders compared to control groups. For example, several studies using the Go/No-Go task reported a larger percentage of commission errors (failure to suppress the prepotent behavioural response on No-Go trials) among offenders compared to non-offenders (C. Y. Chen et al., 2008; Munro et al., 2007a; Ross & Hoaken, 2011; Schiffer & Vonlaufen, 2011). In contrast, two studies focused on psychopathic offenders (i.e., individuals exhibiting a trait reflecting an unemotional, callous, and manipulative interpersonal style) did not find significant differences on the Go/No-Go task between prisoners with psychopathy and prisoners without psychopathy (Freeman et al., 2015; Kiehl, Smith, Hare, & Liddle, 2000). In continuous analyses, indices of self-control on the Go/No-Go task predicted short-term (6 months) but not long term (6-12 months) reoffending in a US sample of 930 male first-time juvenile offenders (Fine, Steinberg, Frick, & Cauffman, 2016). Finally, decreased brain activation during Go/No-Go performance predicted risk of reoffending up to 4 years later (Aharoni et al., 2013).

Studies using the Stop-Signal Task also reported significant impulse control deficits among offenders relative to controls. For instance, Vilà-Balló et al. (Vilà-Balló, Hdez-Lafuente, Rostan, Cunillera, & Rodriguez-Fornells, 2014) found that male juvenile violent offenders made an increased number of inhibitory errors (e.g., failure to suppress the behavioural response following a "stop" cue) and had a significantly shorter stop-signal reaction time, indicating greater difficulty canceling the response, compared to non-offender controls who were matched based on sex, age, and IQ. Similar differences were reported in a sample of adult violent offenders in Taiwan (C.-Y. Chen, Muggleton, & Chang, 2014a).

Two studies compared CPT performance between offenders and controls (Kavanagh, Rowe, Hersch, Barnett, & Reznik, 2010; Meier, Perrig, & Koenig, 2012). Both studies found that the offender groups made a higher percentage of inhibitory errors on the CPT compared to non-offender healthy controls.

In the case of the Stroop task, a meta-analysis by Joyal et al. (Joyal, Beaulieu-Plante, & de Chantérac, 2014) integrating findings across studies of sex offenders, non-sex offenders, and non-offenders found that sex offenders performed worse on the Stroop task compared to controls, but sex and non-sex offender groups did not significantly differ. Differences in Stroop performance between male inmates and controls have also been reported (Kavanagh et al., 2010). However, not all studies have found significant deficits on the Stroop task. Specifically, Schiffer et al. (Schiffer et al., 2014) compared Stroop performance between violent offenders with substance use disorders and non-offenders with history of substance use disorders. Their results indicated that the groups were not significantly different in terms of error rates. Interestingly, in terms of reaction times, the offender group showed a smaller Stroop interference effect relative to non-offenders.

Studies examining inhibitory control among offender samples have reported increased impulse control deficits compared to control participants, including difficulty withholding inappropriate responses and canceling responses once initiated. By comparison, findings for impulse control under interference are somewhat mixed.

Findings with Impulsivity and Risk-taking Measures (Domain 2)

Impulsive decision-making, as indexed by a delay discounting task, was examined in six studies. With the exception of one study (Brennan, Moore, & Shepherd, 2010), all of the studies reported significantly greater delay discounting (i.e., increased impulsivity) among offenders relative to control groups. For instance, in two studies, Cherek et al (Cherek & Lane, 1999; Cherek, Moeller, Dougherty, & Rhoades, 1997) reported that violent parolees made significantly more choices for smaller-immediate rewards over larger-delayed rewards relative to nonviolent parolees. In another study, steeper delay discounting was correlated with the number of previous incarcerations in a sample of US inmates (Varghese, Charlton, Wood, & Trower, 2014).

Results of studies investigating risk-taking measures are less consistent. One study of first-time offenders found significant differences between offenders and controls on the IGT, such that the offenders did not learn to choose from the advantageous decks over time (Yechiam et al., 2008). That study also included comparison groups of chronic cocaine users and patients with orbitofrontal cortex damage. Similar to the offenders, both of these groups failed to learn the advantageous decks on the task. However, another study of IGT performance in recently released male offenders found no significant differences between offenders and controls (Beszterczey, Nestor, Shirai, & Harding, 2013). The literature search only identified one study that included a measure that resembled a probability discounting task (Prehn et al., 2013). In that study, violent criminal offenders with ASPD did not exhibit group differences on preferences for risky choices compared to noncriminal healthy controls, although a subgroup of emotionally hyper-reactive offenders made significantly more risky choices than controls.

Findings in the impulsive choice and risk-taking domain indicated that offenders generally tend to make impulsive choices for immediate rewards relative to delayed rewards. However, performance on laboratory tasks of risk-taking are inconsistent, with some studies finding increased risk taking among offenders and others showing no differences.

Can any of these technologies contribute to novel treatment approaches? E.g., there are labs in Canada experimenting with the use of avatars in treatment for some mental health disorders. We do role plays in group with offenders so they can practice their skills – would any of these approaches assist in this?
(e.g., UQO Cyberlab

Discussion

The objective of this systematic review was to compile the evidence for deficits in impulse control among individuals in the correctional system with a focus on inhibitory control, impulsive choice, and risk-taking tasks. Our primary focus was technology-based measures of these domains, primarily consisting of behavioural performance on tasks assessing response inhibition and choices between rewards. The identified studies spanned a wide geographic area that included a range of institutional settings, offender types, and behavioural measures. Examining the studies collectively, this review suggests a number of general observations and potential conclusions, as discussed below:

- Taken together, the results largely support the general conclusion that offenders exhibit deficits in impulse control relative to non-offenders, but with some notable exceptions. Findings for inhibitory control tasks and impulsive choice paradigms were more consistent than tasks measuring interference or risk-taking. This indicates that, compared to controls, offenders exhibited difficulties with suppressing or canceling unwanted or inappropriate behavioural responses. The offenders also exhibited difficulties in delaying gratification, as evidenced by a greater propensity to choose smaller-immediate rewards over larger-delayed rewards.

- The review also suggests that impulse control deficits may be especially pronounced in certain subgroups of offenders. For example, several of the studies that focused specifically on violent offenders (C.-Y. Chen et al., 2014a; C. Y. Chen et al., 2008; Cherek & Lane, 1999; Cherek et al., 1997; De Brito, Viding, Kumari, Blackwood, & Hodgins, 2013; Munro et al., 2007a; Vilà-Balló et al., 2014) or sex offenders (Schiffer & Vonlaufen, 2011) reported significantly greater inhibitory failures and impulsive choices compared to other types of offenders or control groups. Further understanding how impulse control varies across type of offense is an important area for future research.

- The findings are also somewhat consistent with the notion that impulse control deficits may be a risk factor for future criminal behaviour. For instance, poor response inhibition predicted reoffending over a 6-month period in one study (Fine et al., 2016). Go/No-Go performance also predicted risk of re-arrest in two studies (Aharoni et al., 2013; Steele et al., 2015). A large longitudinal study of risk factors among Swedish children found impulsive delay discounting at age 13 prospectively predicted criminal behaviour in adulthood (Åkerlund et al., 2016). Interestingly, longitudinal studies in the area of addiction have also found that steeper discounting among children predicts initiation of alcohol and drug use later in life (Ayduk et al., 2000; Dom, D'Haene, Hulstijn, & Sabbe, 2006; Kollins, 2003). These findings suggest that performance on technology-based impulse control measures could be investigated as a screening tool to predict risk of future criminal involvement.

- A number of the studies included in the review examined offenders with various forms of psychopathology, including psychopathy and antisocial-personality disorder. However, findings were mixed as to whether subsets of offenders with a clinical diagnosis performed significantly worse than those without a psychiatric diagnosis. Given the relatively limited number of studies focusing on psychiatric disorders in this review, definitive conclusions are not possible. This is an important and promising area for future research.

- The relative lack of studies examining offenders with SUD was another important finding of our review. In fact, only two studies included offenders or drug court participants with SUD (Jones, Fearnley, Panagiotopoulos, & Kemp, 2015; Schiffer et al., 2014). While this does not necessarily mean that offenders in the other studies did not have current or prior history of substance use, the role of substance use was either not reported or not an explicit focus of the study. The absence of studies on impulse control deficits among offenders who exhibit substance use problems is a major gap in the literature.

Strengths and Limitations

The findings of this review should be considered in the context of its strengths and weaknesses. Strengths of this review include a comprehensive literature search strategy that included a wide range of search terms related to impulse control and offending. By casting a broad net, the protocol identified a large number of potential studies that were subjected to a selection process that followed best practices (i.e., PRISMA guidelines). The review also focused on extensively validated “gold-standard” computerized measures of impulse control. Limitations of the review included a relatively small number of studies for some of the measures (e.g., Stroop or IGT performance) and a limited number of studies with female offenders. Another important limitation concerns relatively small sample sizes across studies, with several notable exceptions. Over half (58%) of the studies included in the review had 30 or fewer offenders overall or in the sub-groups examined. While this is certainly understandable given the significant methodological and ethical challenges in conducting research with incarcerated individuals, an important goal for future research is to conduct studies with larger samples. Doing so will likely require collaborative teams of investigators collecting data across multiple institutions.

Part 2: Neuroimaging Approaches to Examining Neural Correlates of Impulse Control in Offenders

This section of the review discusses application of structural and functional brain imaging technologies to investigate the neural correlates of impulse control among offenders and other justice-involved individuals. This section is not intended to be an exhaustive review of all published studies in this area. For a comprehensive discussion of the literature, the reader is encouraged to consult several systematic reviews and meta-analyses that have been recently published (Bufkin & Luttrell, 2005; Yang & Raine, 2009). Instead, our goals are as follows: (1) briefly review the various neuroimaging techniques used in contemporary research, including the pros and cons of each technique; (2) discuss findings from representative studies in offender samples as examples of how these techniques can be used to understand impulse control in this population; and (3) outline future directions in this area.

Functional and Structural Neuroimaging Techniques

Technological advancements in the biomedical sciences and cognitive neuroscience have led to the development of multiple non-invasive neuroimaging techniques, including structural and functional magnetic resonance imaging and electroencephalography. Each methodology provides unique information about brain structure and function. The most commonly used methods include structural magnetic resonance imaging, functional magnetic resonance imaging, and electroencephalography.

Magnetic Resonance Imaging (MRI) is one of the oldest and most widely-used neuroimaging methods for examining brain anatomy. In this technique, participants lay inside an MRI system that uses multiple high-powered magnetic fields to create detailed 3-dimensional images of tissue structure. Structural MRI allows researchers to quantify differences in brain anatomy at incredibly high spatial resolution (e.g., ~1mm resolution). An important advantage of MRI over other structural imaging techniques (e.g., computerized tomography, CT) is that no radiation or injection of contrast chemicals is required. MRI also provides structural images of the entire brain in multiple orientations, including subcortical areas located deep inside the brain.

Functional MRI (fMRI) is a variant of the traditional MRI technique that collects information about brain function. The same MRI machine is used, but in the case of fMRI participants are typically asked to complete some form of computerized task (e.g., press a key when you see an image, watch a video, respond to a question, etc.). As the patient completes the task, the fMRI scanner is quantifying differences in blood flow between different brain regions, with the underlying assumption that brain areas that are active during a particular task are using increased amounts of oxygen-rich blood relative to other areas that are not involved with preforming the task. This is why the primary signal examined during an fMRI scan is known as the blood-oxygen-level-dependent (BOLD) signal. In general, fMRI has superior spatial resolution compared to other functional neuroimaging methods such as EEG, but is only able to infer brain activity on a timescale of several seconds due to the time lag in cerebral blood flow.

Electroencephalography (EEG) is an electrophysiological technique that quantifies brain activity without directly collecting information about brain structure. In a typical EEG experiment, the participant's head is covered with a large array of electrodes that measure electrical activity on the scalp. Modern EEG systems use "sensor nets" with as many as 256 individual electrodes that provide whole-head coverage. Rather than forming a neuroanatomical image, EEG provides a graph visually similar to that of a heart rate monitor with multiple lines of electrical activity across time that correspond to different frequency bands (e.g., alpha waves, beta waves, delta waves, etc.). In cognitive neuroscience research, EEG has been most useful in the context of studying event-related potentials (ERPs), or changes in electrical voltages in response to specific stimuli or behavioural responses. While EEG is less precise in terms of spatial location, the primary advantage of EEG is near real-time temporal precision about the timing of neural activity (often on the order of milliseconds).

Three common neuroimaging techniques include structural MRI (providing detailed images of brain structure with high spatial resolution), fMRI (providing location of brain activation with high spatial resolution and moderate temporal resolution), and EEG (providing highly precise measurement of timing and synchronization of brain activity with relatively limited spatial resolution).

Representative Neuroimaging Studies on Impulse Control in Offender Samples

Neuroimaging studies in offender samples date back to the early-to-mid 1990s. Much of this early work focused on understanding differences in brain metabolism between offenders and non-offenders. For example, a series of studies by Raine and colleagues (Raine et al., 1994; Raine, Buchsbaum, & Lacasse, 1997) found that murderers showed lower glucose metabolism in both lateral and medial prefrontal cortex relative to controls. Reduced brain metabolism was also observed in parietal cortex and subcortical areas in the medial temporal lobe (Raine et al., 1997). Research over the last few decades has built on these findings to uncover structural brain abnormalities and differences in functional brain activation and electrophysiological activity during impulse control tasks in offenders compared to controls. The following section reviews findings from a representative sample of recent studies using these neuroimaging techniques (see Table B3 in Appendix B for a summary of included studies).

In the case of structural MRI, systematic reviews and meta-analyses have found consistent evidence of neuroanatomical abnormalities in areas of prefrontal cortex in offenders (Bufkin & Luttrell, 2005; Yang & Raine, 2009). Table B3 includes examples of two structural MRI studies. In the first study, Leutgeb et al. (Leutgeb et al., 2015) compared high-risk violent offenders to people without a history of violence or criminality and found that the prefrontal cortex of the offenders had less grey matter volume (i.e., less cell-dense brain tissue) than the non-offenders. Moreover, atrophy in other frontal regions such as the orbitofronal cortex, was correlated with anti-sociality and risk of violent recidivism (Leutgeb et al., 2015). In the second study, Tiihonen et al. (Tiihonen et al., 2008) examined persistently violent offenders with antisocial personality disorder and SUD and found that, relative to healthy controls, the offenders had reduced gray matter volumes in the frontal lobe and larger white matter volumes in posterior brain regions (parietal and occipital lobes). The authors conclude that larger volumes in posterior brain areas may reflect atypical neurodevelopment that underlies early-onset persistent antisocial and aggressive behavior.

Turning to research conducted using fMRI, studies in offenders have most commonly examined response inhibition and impulsive/risky decision-making. These studies have generally found significant differences in neural communication between the reward-related brain regions (i.e., ventral striatum) and frontal brain regions responsible for planning and inhibitory control (Aharoni et al., 2013; Freeman et al., 2015; Geurts et al., 2016) For example, Guerts et al.

(Geurts et al., 2016) used fMRI to quantify neural responses to reward expectancy in a monetary choice task. They found that criminal behaviour was characterized by enhanced communication between reward-related ventral striatal regions and frontal regions. Guerts et al. concluded that greater reward processing in offenders may explain why offenders are more likely to act impulsively toward rewards compared to non-criminal individuals.

Studies using fMRI have also suggested that differences in neural activation on inhibitory control tasks (Go/No-Go) also may serve as a marker of risk for future criminal behaviour. Specifically, Aharoni et al. (Aharoni et al., 2013) found that decreased error-related brain activation of the anterior cingulate cortex—a brain area widely implicated in conflict processing and motivation—predicted subsequent re-arrest among adult offenders within four years of release. In fact, the odds that an offender with relatively low anterior cingulate activity would be rearrested were approximately double that of an offender with high activity in this region. Similarly, studies using delay and probability discounting tasks have found an imbalance in neural activation between subcortical reward areas and cortical areas responsible for executive control. Specifically, Hosking et al. (Hosking et al., 2017) found that psychopathy among male offenders was associated with stronger subjective value-related activity in the ventral striatum. Psychopathy was also associated with decreased functional connectivity between ventral striatum and prefrontal cortex, and this diminished connectivity predicted more frequent criminal convictions. In a different study, Prehn et al. (Prehn et al., 2013) found that emotionally hypo-reactive violent offenders had significantly reduced activation of anterior cingulate and prefrontal cortex during probability discounting choices. Deficits in prefrontal cortex activation were most evident when participants were asked to choose the safe alternative, which may explain why offenders often display difficulties selecting safe over unsafe behaviours.

Interestingly, this pattern of over-activity in reward areas and dysfunction in frontal brain areas is consistent with contemporary neurobiological theories of addictive disorders that emphasize a similar imbalance (Bechara, 2005; W K Bickel et al., 2007). For example, in a series of neuroimaging studies on delay discounting decision-making, individuals with alcohol or stimulant use disorders exhibited increased neural activation in regions of the prefrontal cortex relative to healthy controls (e.g., Amlung, Sweet, Acker, Brown, & MacKillop, 2014; Hoffman et al., 2006; Monterosso et al., 2007). This pattern may appear counterintuitive because the clinical group actually showed greater brain activity and not a deficit. However, the interpretation of this pattern of over-activation is that there may be an underlying inefficiency in neural processing in prefrontal regions in people with SUD. Therefore, in order to overcome this deficit, the control centres of the brain located in prefrontal cortex must work extra hard (observed as greater neural activation on a brain imaging scan) to suppress reward areas that are biasing behaviour toward immediate rewards.

The majority of EEG research conducted with offenders has aimed to understand how differences in the magnitude and timing of brain responses contribute to deficits in inhibitory control. By comparison, there are few studies of impulsive decision-making or risk-taking. EEG recording during Go/No-Go and stop signal task performance has revealed that offenders have reduced overall ERP amplitudes and decreased amplitudes of specific ERP sub-components related to cognitive control and inhibition (Maurer, Steele, Edwards, et al., 2016; Munro et al., 2007a). Although spatial resolution is somewhat limited in EEG, sophisticated data modeling techniques have localized these abnormalities to the frontal lobes (C.-Y. Chen et al., 2014a; Munro et al., 2007b). Offenders also show deficits in specific facets of the ERP related to error monitoring and post-error processing (Maurer, Steele, Edwards, et al., 2016; Vilà-Balló et al., 2014). This activity is critical for adjusting behaviour following incorrect behavioural responses, which may partly explain why offenders are more likely to make errors on behavioural tasks than controls.

Structural MRI studies have revealed consistent evidence of decreased brain volume in the frontal lobes and potentially larger posterior brain regions. Functional MRI studies suggest that offenders exhibit an imbalance between subcortical reward areas and cortical executive areas, similar to people with addictive disorders. These reductions may underlie to difficulty controlling behaviour. Finally, EEG studies suggest that inhibitory deficits are explained, in part, by decreased amplitude of frontal lobe neural activity during inhibitory control.

Conclusions and Future Directions

The use of neuroimaging and electrophysiological techniques in offenders is still relatively limited and significant gaps remain in the extant literature. Research on specific subpopulations of offenders, such as juvenile and female offenders, is generally lacking.

Research comparing juvenile offenders to adult offenders may be especially worthwhile to understanding the role of neurodevelopmental deficits in criminal behaviour. The published studies are nearly all focused on inhibitory control tasks such as the Go/No-Go and stop-signal tasks. By comparison, neuroimaging studies of risk-taking tasks such as the IGT were absent, which is unfortunate given the deficits exhibited by offenders on the types of risk-taking tasks reviewed in Part 1. Expanding the use of neuroimaging and electrophysiological technology to the study of a greater range of offender samples and impulse control tasks is a priority for future research. Finally, most studies reviewed here used cross-sectional designs that do not address whether brain deficits are a cause or consequence of criminal involvement, although a few prospective studies did indicate that brain activity patterns could predict subsequent risk of reoffending over time.

Collectively, three general conclusions can be drawn from the neuroimaging research conducted to date:

1) In terms of brain structure, several studies have indicated that offenders have decreased grey matter volume (cell density) in various brain regions, including the frontal regions of the brain responsible for planning and behavioural control. The consistency of these findings across samples and types of offenders suggests this is a relatively robust relationship.
2) In terms of functional brain activation, offenders demonstrate abnormal neural communication between reward-related regions of the brain and frontal brain regions responsible for planning and behavioural control, along with heightened brain responses in reward areas, thus resulting in increased impulsivity and poor ability to inhibit improper behaviour.
3) In terms of electrophysiology, when offenders are attempting to inhibit and control their behaviour, they exhibit deficits in the amplitude of brain responses that typically ensure successful inhibition. They also show dysfunction in feedback and adjustment processes that are engaged following response errors.

Part 3: Novel Technology-Based Treatment for Addictive Disorders

This section will provide an overview of emerging technology-based interventions for addictive disorders. First, we discuss the growth of internet-based interventions and smartphone/tablet-based apps with a focus on their implementation in correctional settings (including post-incarceration settings, such as parole). Next, we provide an overview of recent applications of virtual reality technology to the treatment of addictive disorders. Both of these categories of interventions are increasingly being used to increase self-efficacy and reduce drug/alcohol cravings in individuals with addictive disorders. As in Part 2, our goal is to provide a snapshot of high-quality empirical research in this area rather than a comprehensive literature review. Where available, citations for recent systematic reviews and meta-analyses are provided in the following sections. Moreover, although most of the studies to date have been conducted in non-offender samples, we identified a limited number of studies with offenders that support the promise of these techniques in correctional settings.

Mobile Interventions for Addictions

Implementing substance use treatment in correctional environments carries unique challenges. A primary barrier to providing treatment is cost, with many interventions being expensive to implement and requiring staffing and financial resources that may not be available within correctional settings (Chaple et al., 2016). Another challenge to implementing evidence-based care is the decentralized nature of corrections, which leads to difficulty in ensuring fidelity of the intervention (Canadian Centre on Substance Abuse, 2004; Chaple et al., 2016). According to a 2004 report by the Canadian Centre on Substance Abuse (Canadian Centre on Substance Abuse, 2004), many substance use interventions provided to offenders have been developed "without a clear theoretical base, empirical evidence, or strong adherence to accepted best practice guidelines" (p. 6). Thus, the efficacy of these interventions varies widely and may not be in line with current evidence-based treatments.

Research on effective prison-based substance use treatments indicates that the optimal intervention incorporates different treatment modalities that are tailored to individual differences, taking into account varying learning styles and personal factors (Canadian Centre on Substance

Abuse, 2004). Indeed, tailoring has been shown to increase the effectiveness of numerous types of health messages (Hoeppner et al., 2017). Moreover, effective treatments are those that are delivered consistently and that offer the possibility of community-based follow-up (Canadian Centre on Substance Abuse, 2004). Technology-based interventions involve treatment delivered through various modalities, including structured internet-based programs, smartphone apps, and video-conferencing with a clinician. For a recent critical analysis of smartphone apps for managing alcohol use, see Hoeppner et al. (Hoeppner et al., 2017). Due to the flexible nature of technology-based interventions, they can provide individualized, consistent treatment and have several advantages over traditional in-person treatment (see (Chebli, Blaszczynski, & Gainsbury, 2016)). First, the convenience of these interventions helps to overcome barriers to in-person counselling, whether these are logistical (e.g., transportation, geographical remoteness, etc.) or individual (e.g., unwillingness to get treatment due to stigma or embarrassment). The convenience associated with these interventions also allows for flexibility of treatment access, reducing treatment attrition. Furthermore, these interventions can be more cost-effective in that they can provide services to a large number of people without the associated increases in cost. Lastly, the Internet provides a powerful platform for collecting data on program use, completion, and other measures so that empirical evaluation can occur.

A representative sample of innovative uses of internet and mobile technology for treating addictions is presented in Table B4 in Appendix B (studies in correctional settings are marked with asterisks). For a comprehensive review, see the recent meta-analyses by Hoch et al. (Hoch, Preuss, Ferri, & Simon, 2016) and Boumparis et al. (Boumparis, Karyotaki, Schaub, Cuijpers, & Riper, 2017). Overall, technology-based interventions are rated as easy to use and perceived as more interesting, useful, and satisfying than traditional in-person treatment (Chaple et al., 2014; Guarino, Acosta, Marsch, Xie, & Aponte-Melendez, 2016; King, Brooner, Peirce, Kolodner, & Kidorf, 2014). Better treatment outcomes are related to greater usage of these tools (K. M. Carroll et al., 2008; DeVito, Kiluk, Nich, Mouratidis, & Carroll, 2018; Dulin, Gonzalez, & Campbell, 2014; Gonzalez & Dulin, 2015). Evidence for improving treatment retention is mixed, with some studies reporting greater attrition with mobile/internet interventions groups compared with controls (e.g., (Brendryen et al., 2014)) but other studies showing either similar or better retention than in-person treatment (e.g., (Campbell et al., 2014)). Evidence for the efficacy of these interventions is favorable, with most studies reporting equivalent or improved treatment outcomes compared with treatment-as-usual. For example, several studies have examined the efficacy of a computer-based training for cognitive behaviour therapy program entitled "CBT4CBT" which teaches skills and strategies using games and quizzes. Compared with individuals receiving treatment-as-usual, CBT4CBT groups experienced significantly higher abstinence rates (K. M. Carroll et al., 2008, 2014) and a more rapid reduction in use (Kiluk et al., 2016). CBT4CBT showed a continued benefit at a 6-month follow-up (K. M. Carroll et al., 2014; Kiluk et al., 2016). This is a highly promising strategy as it could be implemented in a correctional setting in a relatively homogeneous way. Future clinical trials of CBT4CBT in correctional settings are needed. Another study (Campbell et al., 2014) compared two groups of addiction treatment-seeking outpatients randomized to either use a computer-based psychosocial education program or to continue with treatment as usual. For patients with a good prognosis at baseline, both conditions achieved similar, high rates of abstinence. In patients with a poor baseline prognosis however, the technology-based intervention doubled the odds of abstinence.

Virtual Reality Interventions

The use of virtual reality (VR) techniques to treat psychological disorders has been increasing over the last decade. Much of the early work using VR in the 1990s focused on application of virtual reality to treat specific phobias (e.g., fear of flying, fear of heights, etc.) or post-traumatic stress disorders (PTSD). More recently, the use of VR has expanded to include eating disorders, psychotic disorders, social anxiety, and addictions, among others (for reviews of the clinical applications of VR, see Gaggioli, Mantovani, Castelnuovo, Wiederhold, & Riva, 2003; Glanz, Rizzo, & Graap, 2003). In many of these disorders, real-world exposure to triggering stimuli or situations may be too intense or unsafe for the individual. Virtual environments, on the other hand, enable clinicians and researchers to simulate events and situations that can be "turned off" instantly in the event of an adverse reaction. In the case of addictions, virtual environments allow for the creation of realistic (and potentially high-risk) situations that typically induce cravings, such as a simulated bar setting or a virtual crack house. Numerous studies have shown virtual reality cue exposure therapy to be effective in decreasing craving in alcohol and nicotine use disorders (Girard, Turcotte, Bouchard, & Girard, 2009; J.-H. Lee, Kwon, Choi, & Yang, 2007; J. Lee et al., 2004; S. H. Lee et al., 2009). In addition to craving, a few studies have reported decreases in actual consumption behaviour following virtual reality interventions (J.-H. Lee et al., 2007; S. H. Lee et al., 2009; Moon & Lee, 2009). Finally, in studies directly comparing virtual reality to traditional cognitive behavioural therapy, the virtual intervention was either equally effective (Park et al., 2014) or in some cases more effective (Culbertson, Shulenberger, De La Garza, Newton, & Brody, 2012; S. H. Lee et al., 2009).

Applications in Correctional Settings

Despite the growing popularity and evidence of efficacy of these technology-based interventions, their application to corrections remains limited due to unique challenges to implementation within these settings. Two recent studies (Chaple et al., 2014, 2016) examined the feasibility and efficacy of a computer-based program in correctional facilities. Results showed that the program was equally as effective as standard care in reducing re-incarceration, criminal activity, and substance use, and improving coping skills. Another pilot study by Johnson and colleagues (Johnson et al., 2016) investigated the feasibility of using a mobile app for recovery support and relapse prevention in a Massachusetts drug court program. Although clinical outcomes were not evaluated, over the course of the four-month study period, participants engaged with the app on 62% of days. Social networking tools embedded in the app were the most frequently used feature of the program. Determining whether use of the app results in significant reductions in drug use clearly requires direct study.

Application of virtual reality in correctional settings is also relatively limited to date; however, two recent reviews emphasized the unique potential for virtual reality in this context (Ticknor & Tillinghast, 2011; van Gelder, Otte, & Luciano, 2014). These authors argue that virtual reality can be helpful in modeling, role playing, and as a means of providing instant feedback. Virtual reality may also help with reintegration following release. However, there are several important challenges in correctional settings including significant start-up costs and the need for advanced technological training. Nevertheless, one study investigated the use of virtual reality in the context of domestic violence (Seinfeld et al., 2018). Male domestic violence offenders underwent a virtual reality experience involving a first-person perspective of a woman undergoing abuse. Following the experience, the offenders showed improved ability to recognize fear in female faces and reduced likelihood of misattributing happiness to fearful facial expressions (i.e., improvements in emotion recognition and discrimination). To our knowledge, no studies have used virtual reality as a treatment for addictive disorders in an offender population.

Technology-based interventions show promise as an emerging treatment modality. As evidenced by the literature, the value in these interventions may not as a replacement for traditional treatment modalities but rather as a supplement to expand rapid access to treatment, to improve treatment retention, and to allow for consistent delivery of treatment and provide ongoing support. Due to the growing nature of this area of research and the unique challenges inherent in correctional settings, further research is needed to clarify the feasibility and efficacy of these interventions.

Emerging technological innovations in the treatment of addictive disorders include the development of Internet and computer-based treatment programs, mobile applications, and virtual reality interventions. Preliminary research on implementation of internet/mobile interventions in corrections settings indicates that these programs offer unique advantages, including rapid and consistent access to evidence-based treatments. By comparison, research on virtual reality applications in corrections is lacking. Continued research on these innovations, including randomized clinical trials, is clearly needed.

Discussion and Conclusions

The overall goals of this report were to provide a critical review of technological assessment of impulse control in offenders, to summarize the current knowledge about the underlying brain basis of these deficits, and to illustrate recent innovative uses of technology in the treatment of addictive disorders. The focus on impulse control was motivated by the fact that prior research has consistently implicated impulse control problems in criminal behaviours and problematic substance use. However, much less is known about impulse control among offenders with SUD. Taken together, the literature reviewed in this report provides relatively consistent and compelling evidence that offenders exhibit difficulty inhibiting responses and delaying gratification on behavioural tasks of impulse control. Interestingly, these deficits have also been shown to predict risk of reoffending up to four years after release. From the brain perspective, the neuroimaging literature on offenders is generally consistent with a neurobiological model that implicates an imbalance between neural processing in subcortical reward/motivation areas (e.g., the ventral striatum) and cortical cognitive/executive control areas (e.g., the prefrontal cortex). Enhanced neural processing in reward areas paired with diminished executive control likely contributes to impulse control problems in offenders.

A secondary goal of this report was to identify gaps in the literature that represent key areas for future research. Despite a comprehensive literature search strategy, only two behavioural studies on impulse control were identified that included offenders with SUD. Unfortunately, the absence of research in this sub-population of offenders precludes any definitive conclusions about the interaction between impulse control, criminal behaviour, and substance use. This is therefore an important area for future research. Another priority is to expand research on specific sub-types of offenders (e.g., violent vs. non-violent offenders; juvenile offenders; female offenders) and offenders with various forms of psychopathology. Finally, additional research is needed to critically evaluate the efficacy of technology-based interventions for addiction in correctional settings.

Despite these gaps in the literature, the present review illustrates the relatively high rates of impulse control deficits among offenders and suggests a central role of prefrontal cortex dysfunction in these deficits. Given the role of impulse control problems in addictive disorders and criminal behaviour, further research to understand the interaction of these factors would increase knowledge and point to how to intervene to manage and treat individuals involved in the criminal justice system.

References

Aharoni, E., Vincent, G. M., Harenski, C. L., Calhoun, V. D., Sinnott-Armstrong, W., Gazzaniga, M. S., & Kiehl, K. A. (2013). Neuroprediction of future rearrest. *Proceedings of the National Academy of Sciences of the United States of America*, *110*(15), 6223–8. https://doi.org/10.1073/pnas.1219302110

Åkerlund, D., Golsteyn, B. H. H., Grönqvist, H., & Lindahl, L. (2016). Time discounting and criminal behavior. *Proceedings of the National Academy of Sciences*, *113*(22), 6160–6165. https://doi.org/10.1073/pnas.1522445113

Amlung, M., Sweet, L. H., Acker, J., Brown, C. L., & MacKillop, J. (2014). Dissociable brain signatures of choice conflict and immediate reward preferences in alcohol use disorders. *Addiction Biology*, *19*(4), 743–753. https://doi.org/10.1111/adb.12017

Amlung, M., Vedelago, L., Acker, J., Balodis, I., & MacKillop, J. (2016). Steep delay discounting and addictive behavior: a meta-analysis of continuous associations. *Addiction (Abingdon, England)*. https://doi.org/10.1111/add.13535

Ayduk, O., Mendoza-Denton, R., Mischel, W., Downey, G., Peake, P., & Rodriguez, M. (2000). Regulating the interpersonal self: Strategic self-regulation for coping with rejection sensitivity. . *J Pers Soc Psychol*, *79*, 776–792.

Barkley, R. A. (1997). Behavioral inhibition, sustained attention, and executive functions: Constructing a unifying theory of ADHD. *Psychological Bulletin*, *121*(1), 65–94. https://doi.org/10.1037/0033-2909.121.1.65

Bechara, A. (2005). Decision making, impulse control and loss of willpower to resist drugs: a neurocognitive perspective. *Nature Neuroscience*, *8*(11), 1458–63. https://doi.org/10.1038/nn1584

Bechara, A., Damasio, A. R., Damasio, H., & Anderson, S. W. (1994). Insensitivity to future consequences following damage to human prefrontal cortex. *Cognition*, *50*(1–3), 7–15. https://doi.org/10.1016/0010-0277(94)90018-3

Beszterczey, S., Nestor, P. G., Shirai, A., & Harding, S. (2013). Neuropsychology of decision making and psychopathy in high-risk ex-offenders. *Neuropsychology*, *27*(4), 491–497. https://doi.org/10.1037/a0033162

Bickel, W. K., Johnson, M. W., Koffarnus, M. N., MacKillop, J., & Murphy, J. G. (2014). The behavioral economics of substance use disorders: reinforcement pathologies and their repair. *Annual Review of Clinical Psychology*, *10*, 641–77. https://doi.org/10.1146/annurev-clinpsy-032813-153724

Bickel, W. K., Miller, M. L., Yi, R., Kowal, B. P., Lindquist, D. M., & Pitcock, J. A. (2007). Behavioral and neuroeconomics of drug addiction: competing neural systems and temporal discounting processes. *Drug Alcohol Depend*, *90 Suppl 1*, S85-91. https://doi.org/S0376-8716(06)00360-7 [pii] 10.1016/j.drugalcdep.2006.09.016

Bilderbeck, A. C., Farias, M., Brazil, I. A., Jakobowitz, S., & Wikholm, C. (2013). Participation in a 10-week course of yoga improves behavioural control and decreases psychological distress in a prison population. *Journal of Psychiatric Research*, *47*(10), 1438–45. https://doi.org/10.1016/j.jpsychires.2013.06.014

Biro, S. M., & Farrell MacDonald, S. (2015). *Substance Use and Behaviour: The Role of Gender. No RIB 15-01*. Ottawa, ON.

Bornovalova, M. A., Daughters, S. B., Hernandez, G. D., Richards, J. B., & Lejuez, C. W. (2005). Differences in impulsivity and risk-taking propensity between primary users of crack cocaine and primary users of heroin in a residential substance-use program. *Exp Clin Psychopharmacol*, *13*(4), 311–318. https://doi.org/2005-15800-005 [pii]10.1037/1064-1297.13.4.311

Boumparis, N., Karyotaki, E., Schaub, M. P., Cuijpers, P., & Riper, H. (2017). Internet interventions for adult illicit substance users: a meta-analysis. *Addiction (Abingdon, England)*, *112*(9), 1521–1532. https://doi.org/10.1111/add.13819

Brendryen, H., Lund, I. O., Johansen, A. B., Riksheim, M., Nesvåg, S., & Duckert, F. (2014). Balance-a pragmatic randomized controlled trial of an online intensive self-help alcohol intervention. *Addiction*, *109*(2), 218–226. https://doi.org/10.1111/add.12383

Brennan, I. R., Moore, S. C., & Shepherd, J. P. (2010). Aggression and attitudes to time and risk in weapon-using violent offenders. *Psychiatry Research*, *178*(3), 536–9. https://doi.org/10.1016/j.psychres.2009.05.006

Brochu, S., Cousineau, M. M., Gillet, M., Cournoyer, L. G., Pernanen, K., & Motiuk, L. (2002). Drugs, alcohol, and criminal behaviour: A profile of inmates in Canadian Federal Institutions. *Forum on Corections Research*, *13*, 20–24.

Brown, J., Michie, S., Geraghty, A. W., Yardley, L., Gardner, B., Shahab, L., … West, R.

(2014). Internet-based intervention for smoking cessation (StopAdvisor) in people with low and high socioeconomic status: a randomised controlled trial. *The Lancet Respiratory Medicine*, *2*(12), 997–1006. https://doi.org/10.1016/S2213-2600(14)70195-X

Bufkin, J. L., & Luttrell, V. R. (2005). Neuroimaging Studies of Aggressive and Violent Behavior. *Trauma, Violence, & Abuse*, *6*(2), 176–191. https://doi.org/10.1177/1524838005275089

Campbell, A. N. C., Nunes, E. V., Matthews, A. G., Stitzer, M., Miele, G. M., Polsky, D., … Ghitza, U. E. (2014). Internet-Delivered Treatment for Substance Abuse: A Multisite Randomized Controlled Trial. *American Journal of Psychiatry*, *171*(6), 683–690. https://doi.org/10.1176/appi.ajp.2014.13081055

Canadian Centre on Substance Abuse. (2004). *Substance Abuse in Corrections FAQs*. Ottawa, ON.

Carroll, A., Hemingway, F., Bower, J., Ashman, A., Houghton, S., Durkin, K., … Lindahl, L. (2017). Impulsivity in juvenile delinquency: Differences among early-onset, late-onset, and non-offenders. *NeuroReport*, *113*(22), 193–198. https://doi.org/10.1097/00001756-200508010-00016

Carroll, K. M., Ball, S. A., Martino, S., Nich, C., Babuscio, T. A., Nuro, K. F., … Rounsaville, B. J. (2008). Computer-Assisted Delivery of Cognitive-Behavioral Therapy for Addiction: A Randomized Trial of CBT4CBT. *American Journal of Psychiatry*, *165*(7), 881–888. https://doi.org/10.1176/appi.ajp.2008.07111835

Carroll, K. M., Kiluk, B. D., Nich, C., Gordon, M. A., Portnoy, G. A., Marino, D. R., & Ball, S. A. (2014). Computer-Assisted Delivery of Cognitive-Behavioral Therapy: Efficacy and Durability of CBT4CBT Among Cocaine-Dependent Individuals Maintained on Methadone. *American Journal of Psychiatry*, *171*(4), 436–444. https://doi.org/10.1176/appi.ajp.2013.13070987

Chaple, M., Sacks, S., McKendrick, K., Marsch, L. A., Belenko, S., Leukefeld, C., … French, M. (2014). Feasibility of a computerized intervention for offenders with substance use disorders: a research note. *Journal of Experimental Criminology*, *10*(1), 105–127. https://doi.org/10.1007/s11292-013-9187-y

Chaple, M., Sacks, S., McKendrick, K., Marsch, L. A., Belenko, S., Leukefeld, C., … French, M. (2016). A Comparative Study of the Therapeutic Education System for Incarcerated

Substance-Abusing Offenders. *The Prison Journal*, *96*(3), 485–508. https://doi.org/10.1177/0032885516636858

Chebli, J.-L., Blaszczynski, A., & Gainsbury, S. M. (2016). Internet-Based Interventions for Addictive Behaviours: A Systematic Review. *Journal of Gambling Studies*, *32*(4), 1279–1304. https://doi.org/10.1007/s10899-016-9599-5

Chen, C.-Y., Muggleton, N. G., & Chang, J.-R. (2014a). Inefficiency of post-error adjustment in impulsive violent offenders. *NeuroReport*, *25*(13), 1024–1029. https://doi.org/10.1097/WNR.0000000000000212

Chen, C.-Y., Muggleton, N. G., & Chang, J.-R. (2014b). Inefficiency of post-error adjustment in impulsive violent offenders. *NeuroReport*, *25*(13), 1024–1029. https://doi.org/10.1097/WNR.0000000000000212

Chen, C.-Y., Tien, Y.-M., Juan, C.-H., Tzeng, O. J. L., & Hung, D. L. (2005). Neural correlates of impulsive-violent behavior: an event-related potential study. *NeuroReport*, *16*(11), 1213–1216. https://doi.org/10.1097/00001756-200508010-00016

Chen, C. Y., Muggleton, N. G., Juan, C. H., Tzeng, O. J. L., & Hung, D. L. (2008). Time pressure leads to inhibitory control deficits in impulsive violent offenders. *Behavioural Brain Research*, *187*(2), 483–488. https://doi.org/10.1016/j.bbr.2007.10.011

Cherek, D. R., & Lane, S. D. (1999). Laboratory and psychometric measurements of impulsivity among violent and nonviolent female parolees. *Biological Psychiatry*, *46*(2), 273–280. https://doi.org/10.1016/S0006-3223(98)00309-6

Cherek, D. R., Moeller, F. G., Dougherty, D. M., & Rhoades, H. (1997). Studies of violent and nonviolent male parolees: II. Laboratory and psychometric measurements of impulsivity. *Biological Psychiatry*, *41*(5), 523–529. https://doi.org/10.1016/S0006-3223(96)00426-X

Connors, C. K., & MHS Staff. (2000). *Conners' Continuous Performance Test II: Computer Program for Windows Technical Guide and Software Manual*. North Tonawanda, NY: Multi-Health Systems.

Crews, F. T., & Boettiger, C. A. (2009). Impulsivity, frontal lobes and risk for addiction. *Pharmacology, Biochemistry, and Behavior*, *93*(3), 237–47. https://doi.org/10.1016/j.pbb.2009.04.018

Culbertson, C. S., Shulenberger, S., De La Garza, R., Newton, T. F., & Brody, A. L. (2012). Virtual reality cue exposure therapy for the treatment of tobacco dependence. *Journal of*

Cyber Therapy and Rehabilitation, 5(1), 57–64. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/25342999

Dahne, J., Richards, J. M., Ernst, M., MacPherson, L., & Lejuez, C. W. (2013). Assessment of Risk Taking in Addiction Research. In J. MacKillop & H. De Wit (Eds.), *The Wiley-Blackwell Handbook of Addiction Psychopharmacology* (pp. 209–231). West Sussex: Wiley-Blackwell.

De Brito, S. A., Viding, E., Kumari, V., Blackwood, N., & Hodgins, S. (2013). Cool and Hot Executive Function Impairments in Violent Offenders with Antisocial Personality Disorder with and without Psychopathy. *PLoS ONE, 8*(6), e65566. https://doi.org/10.1371/journal.pone.0065566

de Wit, H. (2009). Impulsivity as a determinant and consequence of drug use: a review of underlying processes. *Addiction Biology*, *14*(1), 22–31. https://doi.org/10.1111/j.1369-1600.2008.00129.x

DeVito, E. E., Kiluk, B. D., Nich, C., Mouratidis, M., & Carroll, K. M. (2018). Drug Stroop: Mechanisms of response to computerized cognitive behavioral therapy for cocaine dependence in a randomized clinical trial. *Drug and Alcohol Dependence*, *183*, 162–168. https://doi.org/10.1016/j.drugalcdep.2017.10.022

Diamond, A. (2013). Executive Functions. *Annual Review of Psychology*, *64*(1), 135–168. https://doi.org/10.1146/annurev-psych-113011-143750

Dolan, M. (2012). The neuropsychology of prefrontal function in antisocial personality disordered offenders with varying degrees of psychopathy. *Psychological Medicine*, *42*(8), 1715–1725. https://doi.org/10.1017/S0033291711002686

Dom, G., D'Haene, P., Hulstijn, W., & Sabbe, B. (2006). Impulsivity in abstinent early- and late-onset alcoholics: differences in self-report measures and a discounting task. *Addiction*, *101*(1), 50–59. https://doi.org/ADD1270 [pii] 10.1111/j.1360-0443.2005.01270.x

Dulin, P. L., Gonzalez, V. M., & Campbell, K. (2014). Results of a Pilot Test of a Self-Administered Smartphone-Based Treatment System for Alcohol Use Disorders: Usability and Early Outcomes. *Substance Abuse*, *35*(2), 168–175. https://doi.org/10.1080/08897077.2013.821437

Eriksen, C. W. (1995). The flankers task and response competition: A useful tool for investigating a variety of cognitive problems. *Visual Cognition, 2*(2–3), 101–118.

https://doi.org/10.1080/13506289508401726

Farrell MacDonald, S. (2014a). *Lifetime Substance Use Patterns of Women Offenders. No RS 14-24*. Ottawa, ON.

Farrell MacDonald, S. (2014b). *Severity of Substance Use, Discretionary Release, and Return to Federal Custody. No RS 14-19.* Ottawa, ON.

Farrell MacDonald, S., Gobeil, R., Biro, S. M., Ritchie, M. B., & Curno, J. (2015). *Women Offenders, Substance Use, and Behaviour. No R-358*. Ottawa, ON.

Faunce, G. J., & Job, R. F. (2000). The Stroop colour-naming task and addictive behaviour: some recommendations. *Addiction*, *95*(9), 1438–1442. Retrieved from http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=11048366

Fazel, S., Yoon, I. A., & Hayes, A. J. (2017). Substance use disorders in prisoners : an updated systematic review and meta-regression analysis in recently incarcerated men and women. *Addiction*. https://doi.org/10.1111/add.13877

Fede, S. J., Harenski, C. L., Schaich Borg, J., Sinnott-Armstrong, W., Rao, V., Caldwell, B. M., … Kiehl, K. A. (2016). Abnormal fronto-limbic engagement in incarcerated stimulant users during moral processing. *Psychopharmacology*, *233*(17), 3077–3087. https://doi.org/10.1007/s00213-016-4344-4

Fillmore, M. T. (2003). Drug abuse as a problem of impaired control: current approaches and findings. *Behavioral & Cognitive Neuroscience Reviews*, *2*(3), 179–197. https://doi.org/10.1177/1534582303257007

Fine, A., Steinberg, L., Frick, P. J., & Cauffman, E. (2016). Self-Control Assessments and Implications for Predicting Adolescent Offending. *Journal of Youth and Adolescence*, *45*(4), 701–712. https://doi.org/10.1007/s10964-016-0425-2

Freeman, S. M., Clewett, D. V., Bennett, C. M., Kiehl, K. A., Gazzaniga, M. S., & Miller, M. B. (2015). The posteromedial region of the default mode network shows attenuated task-induced deactivation in psychopathic prisoners. *Neuropsychology*, *29*(3), 493–500. https://doi.org/10.1037/neu0000118

Gaggioli, A., Mantovani, F., Castelnuovo, G., Wiederhold, B., & Riva, G. (2003). Avatars in Clinical Psychology: A Framework for the Clinical Use of Virtual Humans. *CyberPsychology & Behavior*, *6*(2), 117–125.

https://doi.org/10.1089/109493103321640301

Geurts, D. E. M., von Borries, K., Volman, I., Bulten, B. H., Cools, R., & Verkes, R.-J. (2016). Neural connectivity during reward expectation dissociates psychopathic criminals from non-criminal individuals with high impulsive/antisocial psychopathic traits. *Social Cognitive and Affective Neuroscience, 11*(8), 1326–34. https://doi.org/10.1093/scan/nsw040

Girard, B., Turcotte, V., Bouchard, S., & Girard, B. (2009). Crushing Virtual Cigarettes Reduces Tobacco Addiction and Treatment Discontinuation. *CyberPsychology & Behavior*, *12*(5), 477–483. https://doi.org/10.1089/cpb.2009.0118

Glanz, K., Rizzo, A. (Skip), & Graap, K. (2003). Virtual reality for psychotherapy: Current reality and future possibilities. *Psychotherapy: Theory, Research, Practice, Training*, *40*(1–2), 55–67. https://doi.org/10.1037/0033-3204.40.1-2.55

Gonzalez, V. M., & Dulin, P. L. (2015). Comparison of a smartphone app for alcohol use disorders with an Internet-based intervention plus bibliotherapy: A pilot study. *Journal of Consulting and Clinical Psychology*, *83*(2), 335–45. https://doi.org/10.1037/a0038620

Guarino, H., Acosta, M., Marsch, L. A., Xie, H., & Aponte-Melendez, Y. (2016). A mixed-methods evaluation of the feasibility, acceptability, and preliminary efficacy of a mobile intervention for methadone maintenance clients. *Psychology of Addictive Behaviors*, *30*(1), 1–11. https://doi.org/10.1037/adb0000128

Hoch, E., Preuss, U. W., Ferri, M., & Simon, R. (2016). Digital Interventions for Problematic Cannabis Users in Non-Clinical Settings: Findings from a Systematic Review and Meta-Analysis. *European Addiction Research*, *22*(5), 233–242. https://doi.org/10.1159/000445716

Hoeppner, B. B., Schick, M. R., Kelly, L. M., Hoeppner, S. S., Bergman, B., & Kelly, J. F. (2017). There is an app for that – Or is there? A content analysis of publicly available smartphone apps for managing alcohol use. *Journal of Substance Abuse Treatment*, *82*, 67–73. https://doi.org/10.1016/j.jsat.2017.09.006

Hoffman, W. F., Moore, M., Templin, R., McFarland, B., Hitzemann, R. J., & Mitchell, S. H. (2006). Neuropsychological function and delay discounting in methamphetamine-dependent individuals. *Psychopharmacology (Berl)*, *188*(2), 162–170. https://doi.org/10.1007/s00213-006-0494-0

Hosking, J. G., Kastman, E. K., Dorfman, H. M., Samanez-Larkin, G. R., Baskin-Sommers, A., Kiehl, K. A., … Buckholtz, J. W. (2017). Disrupted Prefrontal Regulation of Striatal Subjective Value Signals in Psychopathy. *Neuron*, *95*(1), 221–231.e4. https://doi.org/10.1016/j.neuron.2017.06.030

Johnson, K., Richards, S., Chih, M.-Y., Moon, T. J., Curtis, H., & Gustafson, D. H. (2016). A Pilot Test of a Mobile App for Drug Court Participants. *Substance Abuse: Research and Treatment*, *10*, SART.S33390. https://doi.org/10.4137/SART.S33390

Jones, C. G. A., Fearnley, H., Panagiotopoulos, B., & Kemp, R. I. (2015). Delay discounting, self-control, and substance use among adult drug court participants. *Behavioural Pharmacology*, *26*(5), 447–459. https://doi.org/10.1097/FBP.0000000000000149

Joyal, C. C., Beaulieu-Plante, J., & de Chantérac, A. (2014). The Neuropsychology of Sex Offenders. *Sexual Abuse: A Journal of Research and Treatment*, *26*(2), 149–177. https://doi.org/10.1177/1079063213482842

Kamarajan, C., Porjesz, B., Jones, K. A., Choi, K., Chorlian, D. B., Padmanabhapillai, A., … Begleiter, H. (2005). Alcoholism is a disinhibitory disorder: neurophysiological evidence from a Go/No-Go task. *Biol Psychol*, *69*(3), 353–373. https://doi.org/S0301-0511(04)00153-X [pii]10.1016/j.biopsycho.2004.08.004

Kavanagh, L., Rowe, D., Hersch, J., Barnett, K. J., & Reznik, R. (2010). Neurocognitive deficits and psychiatric disorders in a NSW prison population. *International Journal of Law and Psychiatry*, *33*(1), 20–26. https://doi.org/10.1016/J.IJLP.2009.10.004

Kelly, L., & Farrell MacDonald, S. (2015a). *Comparing Lifetime Substance Use Patterns of Men and Women Offenders. No RIB 14-44.* Ottawa, ON.

Kelly, L., & Farrell MacDonald, S. (2015b). *Lifetime Substance Use Patterns of Men Offenders. No RIB 14-43*. Ottawa, ON.

Kiehl, K. A., Smith, A. M., Hare, R. D., & Liddle, P. F. (2000). An event-related potential investigation of response inhibition in schizophrenia and psychopathy. *Biological Psychiatry*, *48*(3), 210–221. https://doi.org/10.1016/S0006-3223(00)00834-9

Kiluk, B. D., Devore, K. A., Buck, M. B., Nich, C., Frankforter, T. L., LaPaglia, D. M., … Carroll, K. M. (2016). Randomized Trial of Computerized Cognitive Behavioral Therapy for Alcohol Use Disorders: Efficacy as a Virtual Stand-Alone and Treatment Add-On Compared with Standard Outpatient Treatment. *Alcoholism: Clinical and Experimental Research*, *40*(9), 1991–2000. https://doi.org/10.1111/acer.13162

King, V. L., Brooner, R. K., Peirce, J. M., Kolodner, K., & Kidorf, M. S. (2014). A randomized trial of Web-based videoconferencing for substance abuse counseling. *Journal of Substance Abuse Treatment*, *46*(1), 36–42. https://doi.org/10.1016/j.jsat.2013.08.009

Kollins, S. H. (2003). Delay discounting is associated with substance use in college students. *Addictive Behaviors*, *28*(6), 1167–1173. https://doi.org/S0306460302002204 [pii]

Lee, C. A., Derefinko, K. J., Milich, R., Lynam, D. R., & DeWall, C. N. (2017). Longitudinal and reciprocal relations between delay discounting and crime. *Personality and Individual Differences*, *111*, 193–198. https://doi.org/10.1016/j.paid.2017.02.023

Lee, J.-H., Kwon, H., Choi, J., & Yang, B.-H. (2007). Cue-exposure therapy to decrease alcohol craving in virtual environment. *Cyberpsychology & Behavior : The Impact of the Internet, Multimedia and Virtual Reality on Behavior and Society*, *10*(5), 617–23. https://doi.org/10.1089/cpb.2007.9978

Lee, J., Lim, Y., Graham, S. J., Kim, G., Wiederhold, B. K., Wiederhold, M. D., … Kim, S. I. (2004). Nicotine Craving and Cue Exposure Therapy by Using Virtual Environments. *CyberPsychology & Behavior*, *7*(6), 705–713. https://doi.org/10.1089/cpb.2004.7.705

Lee, S. H., Han, D. H., Oh, S., Lyoo, I. K., Lee, Y. S., Renshaw, P. F., & Lukas, S. E. (2009). Quantitative electroencephalographic (qEEG) correlates of craving during virtual reality therapy in alcohol-dependent patients. *Pharmacology Biochemistry and Behavior*, *91*(3), 393–397. https://doi.org/10.1016/j.pbb.2008.08.014

Leutgeb, V., Leitner, M., Wabnegger, A., Klug, D., Scharmüller, W., Zussner, T., & Schienle, A. (2015). Brain abnormalities in high-risk violent offenders and their association with psychopathic traits and criminal recidivism. *Neuroscience*, *308*, 194–201. https://doi.org/10.1016/j.neuroscience.2015.09.011

Logan, G. D. (1994). On the ability to inhibit thought and action: A user's guide to the stop-signal paradigm. In D. Dagenbach & T. H. Carr (Eds.), *Inhibitory Processes in Attention, Memory, and Language* (pp. 189–239). San Diego: Academic Press.

Longshore, D. (1998). Self-Control and Criminal Opportunity: A Prospective Test of the General Theory of Crime. *Social Problems*, *45*, 102–113.

MacKillop, J., Amlung, M. T., Few, L. R., Ray, L. a., Sweet, L. H., & Munafò, M. R. (2011). Delayed reward discounting and addictive behavior: a meta-analysis. *Psychopharmacology (Berl)*, *216*(3), 305–321. https://doi.org/10.1007/s00213-011-2229-0

MacKillop, J., Weafer, J., C. Gray, J., Oshri, A., Palmer, A., & de Wit, H. (2016). The latent structure of impulsivity: impulsive choice, impulsive action, and impulsive personality traits. *Psychopharmacology*, *233*(18), 3361–3370. https://doi.org/10.1007/s00213-016-4372-0

Mann, K., Agartz, I., Harper, C., Shoaf, S., Rawlings, R. R., Momenan, R., … Heinz, A. (2001). Neuroimaging in alcoholism: ethanol and brain damage. *Alcoholism: Clinical and Experimental Research*, *25*(5 Suppl ISBRA), 104S–109S. Retrieved from http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=11391058

Maurer, J. M., Steele, V. R., Cope, L. M., Vincent, G. M., Stephen, J. M., Calhoun, V. D., & Kiehl, K. A. (2016). Dysfunctional error-related processing in incarcerated youth with elevated psychopathic traits. *Developmental Cognitive Neuroscience*, *19*, 70–77. https://doi.org/10.1016/j.dcn.2016.02.006

Maurer, J. M., Steele, V. R., Edwards, B. G., Bernat, E. M., Calhoun, V. D., & Kiehl, K. A. (2016). Dysfunctional error-related processing in female psychopathy. *Social Cognitive and Affective Neuroscience*, *11*(7), 1059–1068. https://doi.org/10.1093/scan/nsv070

Meier, N. M., Perrig, W., & Koenig, T. (2012). Neurophysiological correlates of delinquent behaviour in adult subjects with ADHD. *International Journal of Psychophysiology*, *84*(1), 1–16. https://doi.org/10.1016/J.IJPSYCHO.2011.12.011

Mishra, S., & Lalumière, M. L. (2017). Associations Between Delay Discounting and Risk-Related Behaviors, Traits, Attitudes, and Outcomes. *Journal of Behavioral Decision Making*, *30*(3), 769–781. https://doi.org/10.1002/bdm.2000

Moffitt, T. E., Arseneault, L., Belsky, D., Dickson, N., Hancox, R. J., Harrington, H., … Caspi, A. (2011). A gradient of childhood self-control predicts health, wealth, and public safety. *Proceedings of the National Academy of Sciences*, *108*(7), 2693–2698. https://doi.org/10.1073/pnas.1010076108

Monterosso, J., Ainslie, G., Xu, J., Cordova, X., Domier, C. P., & London, E. D. (2007). Frontoparietal cortical activity of methamphetamine-dependent and comparison subjects performing a delay discounting task. *Hum Brain Mapp*, *28*(5), 383–393. https://doi.org/10.1002/hbm.20281

Moon, J., & Lee, J.-H. (2009). Cue exposure treatment in a virtual environment to reduce nicotine craving: a functional MRI study. *Cyberpsychology & Behavior : The Impact of the Internet, Multimedia and Virtual Reality on Behavior and Society*, *12*(1), 43–5. https://doi.org/10.1089/cpb.2008.0032

Munro, G. E. S., Dywan, J., Harris, G. T., McKee, S., Unsal, A., & Segalowitz, S. J. (2007a). Response inhibition in psychopathy: The frontal N2 and P3. *Neuroscience Letters*, *418*(2), 149–153. https://doi.org/10.1016/J.NEULET.2007.03.017

Munro, G. E. S., Dywan, J., Harris, G. T., McKee, S., Unsal, A., & Segalowitz, S. J. (2007b). Response inhibition in psychopathy: The frontal N2 and P3. *Neuroscience Letters*, *418*(2), 149–153. https://doi.org/10.1016/j.neulet.2007.03.017

Park, C.-B., Choi, J.-S., Park, S. M., Lee, J.-Y., Jung, H. Y., Seol, J.-M., … Kwon, J. S. (2014). Comparison of the effectiveness of virtual cue exposure therapy and cognitive behavioral therapy for nicotine dependence. *Cyberpsychology, Behavior and Social Networking*, *17*(4), 262–7. https://doi.org/10.1089/cyber.2013.0253

Perry, J. L., & Carroll, M. E. (2008). The role of impulsive behavior in drug abuse. *Psychopharmacology (Berl)*, *200*(1), 1–26. https://doi.org/10.1007/s00213-008-1173-0

Prehn, K., Schlagenhauf, F., Schulze, L., Berger, C., Vohs, K., Fleischer, M., … Herpertz, S. C. (2013). Neural correlates of risk taking in violent criminal offenders characterized by emotional hypo- and hyper-reactivity. *Social Neuroscience*, *8*(2), 136–147. https://doi.org/10.1080/17470919.2012.686923

Raine, A., Buchsbaum, M., & Lacasse, L. (1997). Brain abnormalities in murderers indicated by positron emission tomography. *Biological Psychiatry*, *42*(6), 495–508. https://doi.org/10.1016/S0006-3223(96)00362-9

Raine, A., Buchsbaum, M. S., Stanley, J., Lottenberg, S., Abel, L., & Stoddard, J. (1994). Selective reductions in prefrontal glucose metabolism in murderers. *Biological Psychiatry*, *36*(6), 365–373. https://doi.org/10.1016/0006-3223(94)91211-4

Rogers, R., Everitt, B., Baldacchino, A., Blackshaw, A., Swainson, R., Wynne, K., … Robbins, T. (1999). Dissociable Deficits in the Decision-Making Cognition of Chronic Amphetamine Abusers, Opiate Abusers, Patients with Focal Damage to Prefrontal Cortex, and Tryptophan-Depleted Normal Volunteers Evidence for Monoaminergic Mechanisms. *Neuropsychopharmacology*, *20*(4), 322–339. https://doi.org/10.1016/S0893-133X(98)00091-8

Rooke, S., Copeland, J., Norberg, M., Hine, D., & McCambridge, J. (2013). Effectiveness of a Self-Guided Web-Based Cannabis Treatment Program: Randomized Controlled Trial. *Journal of Medical Internet Research*, *15*(2), e26. https://doi.org/10.2196/jmir.2256

Ross, E. H., & Hoaken, P. N. S. (2011). Executive Cognitive Functioning Abilities of Male First Time and Return Canadian Federal Inmates. *Canadian Journal of Criminology and Criminal Justice*, *53*(4), 377–403. https://doi.org/10.3138/cjccj.53.4.377

Schiffer, B., Pawliczek, C., Mu Ller, B., Forsting, M., Gizewski, E., Leygraf, N., & Hodgins, S. (2014). Neural mechanisms underlying cognitive control of men with lifelong antisocial behavior. *Psychiatry Research*, *222*(1–2), 43–51. https://doi.org/10.1016/j.pscychresns.2014.01.008

Schiffer, B., & Vonlaufen, C. (2011). Executive Dysfunctions in Pedophilic and Nonpedophilic Child Molesters. *The Journal of Sexual Medicine*, *8*(7), 1975–1984. https://doi.org/10.1111/j.1743-6109.2010.02140.x

Seinfeld, S., Arroyo-Palacios, J., Iruretagoyena, G., Hortensius, R., Zapata, L. E., Borland, D., … Sanchez-Vives, M. V. (2018). Offenders become the victim in virtual reality: impact of changing perspective in domestic violence. *Scientific Reports*, *8*(1), 2692. https://doi.org/10.1038/s41598-018-19987-7

Shannon, B. J., Raichle, M. E., Snyder, A. Z., Fair, D. A., Mills, K. L., Zhang, D., … Kiehl, K. A. (2011). Premotor functional connectivity predicts impulsivity in juvenile offenders. *Proceedings of the National Academy of Sciences of the United States of America*, *108*(27), 11241–5. https://doi.org/10.1073/pnas.1108241108

Simmonds, D. J., Pekar, J. J., & Mostofsky, S. H. (2008). Meta-analysis of Go/No-go tasks demonstrating that fMRI activation associated with response inhibition is task-dependent. *Neuropsychologia*, *46*(1), 224–232. https://doi.org/S0028-3932(07)00268-0 [pii]10.1016/j.neuropsychologia.2007.07.015

Steele, V. R., Claus, E. D., Aharoni, E., Vincent, G. M., Calhoun, V. D., & Kiehl, K. A. (2015). Multimodal imaging measures predict rearrest. *Frontiers in Human Neuroscience*, *9*, 425. https://doi.org/10.3389/fnhum.2015.00425

Stein, J., & Madden, G. J. (2013). Delay Discounting and Drug Abuse: Empirical, Conceptual, and Methodological Considerations. In J. MacKillop & H. de Wit (Eds.), *The Wiley-Blackwell Handbook of Addiction Psychopharmacology* (pp. 165–208). Oxford: Wiley-

Blackwell.

Stewart, L. A., Clarke, M., Rovers, M., Riley, R. D., Simmonds, M., Stewart, G., & Tierney, J. F. (2015). Preferred Reporting Items for Systematic Review and Meta-Analyses of individual participant data: the PRISMA-IPD Statement. *Journal of the American Medical Association*, *313*(16), 1657–65. https://doi.org/10.1001/jama.2015.3656

Stroop, J. R. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology*, *18*(6), 643–662. https://doi.org/10.1037/h0054651

Sullivan, E. V., & Pfefferbaum, A. (2005). Neurocircuitry in alcoholism: a substrate of disruption and repair. *Psychopharmacology*, *180*(4), 583–594. https://doi.org/10.1007/s00213-005-2267-6

Ticknor, B., & Tillinghast, S. (2011). Virtual Reality and the Criminal Justice System: New Possibilities for Research, Training, and Rehabilitation. *Journal For Virtual Worlds Research*, *4*(2). https://doi.org/10.4101/JVWR.V4I2.2071

Tiihonen, J., Rossi, R., Laakso, M. P., Hodgins, S., Testa, C., Perez, J., … Frisoni N, G. B. (2008). Brain anatomy of persistent violent offenders: More rather than less. *Psychiatry Research: Neuroimaging*, *163*, 201–212. https://doi.org/10.1016/j.pscychresns.2007.08.012

van Gelder, J.-L., Otte, M., & Luciano, E. C. (2014). Using virtual reality in criminological research. *Crime Science*, *3*(1), 10. https://doi.org/10.1186/s40163-014-0010-5

Varghese, F. P., Charlton, S. R., Wood, M., & Trower, E. (2014). Temporal discounting and criminal thinking: Understanding cognitive processes to align services. *Psychological Services*, *11*(2), 171–178. https://doi.org/10.1037/a0035004

Verbruggen, F., & Logan, G. D. (2008). Response inhibition in the stop-signal paradigm. *Trends in Cognitive Sciences*, *12*(11), 418–424. https://doi.org/10.1016/J.TICS.2008.07.005

Vilà-Balló, A., Hdez-Lafuente, P., Rostan, C., Cunillera, T., & Rodriguez-Fornells, A. (2014). Neurophysiological correlates of error monitoring and inhibitory processing in juvenile violent offenders. *Biological Psychology*, *102*(1), 141–152. https://doi.org/10.1016/j.biopsycho.2014.07.021

Weekes, J. R., Millson, W. A., Porporino, F. J., & Robinson, D. (1994). *The offender Substance Abuse Pre-Release Program: Intermediate and post-release outcomes*. Ottawa.

Wilbertz, T., Deserno, L., Horstmann, A., Neumann, J., Villringer, A., Heinze, H.-J., … Schlagenhauf, F. (2014). Response inhibition and its relation to multidimensional impulsivity. *NeuroImage*, *103*, 241–248. https://doi.org/10.1016/J.NEUROIMAGE.2014.09.021

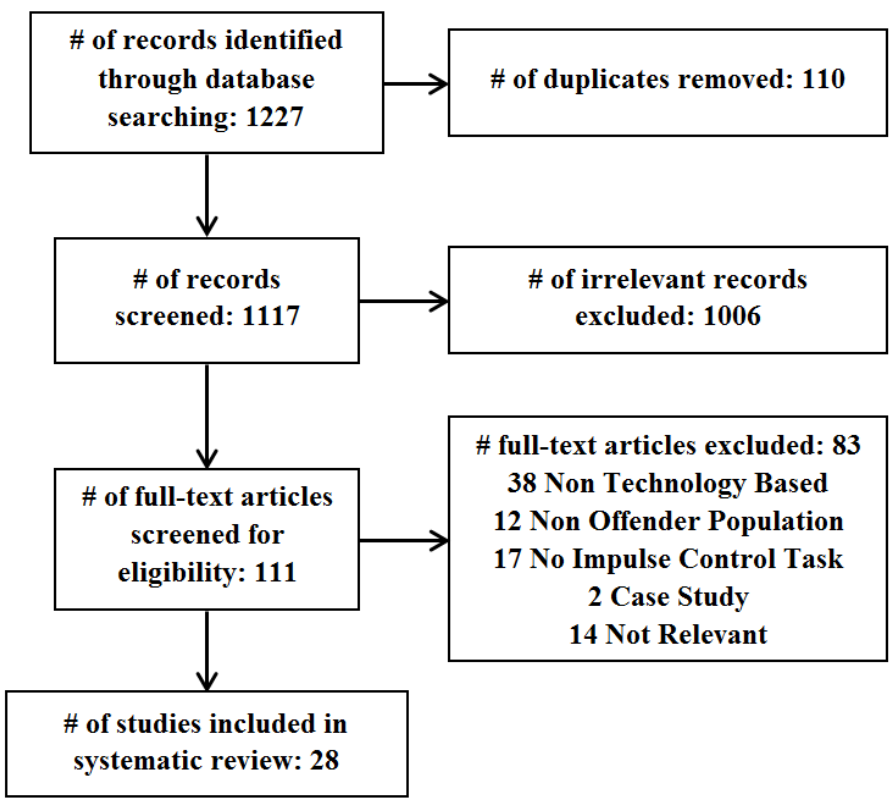
Yang, Y., & Raine, A. (2009). Prefrontal structural and functional brain imaging findings in antisocial, violent, and psychopathic individuals: A meta-analysis. *Psychiatry Research: Neuroimaging*, *174*(2), 81–88. https://doi.org/10.1016/J.PSCYCHRESNS.2009.03.012

Yechiam, E., Kanz, J. E., Bechara, A., Stout, J. C., Busemeyer, J. R., Altmaier, E. M. M., & Paulsen, J. S. (2008). Neurocognitive deficits related to poor decision making in people behind bars. *Psychonomic Bulletin & Review*, *15*(1), 44–51. https://doi.org/10.3758/PBR.15.1.44

Appendix A

Figure 1. Study Selection PRISMA Diagram

Flow chart depicting study selection process following PRISMA standards. Of 1117 unique records, 1006 were deemed irrelevant based on title and abstract review. Of the remaining 111 articles, 83 were excluded based on full-text review, for the reasons provided below. The final systematic review included 28 studies.



Appendix B

Table B1.

Summary of Studies Investigating Inhibitory Control in Offender Samples

Study	Population	Country	Setting	Measures Used	Main Findings
(Aharoni et al., 2013)	Male offenders (*N*=96); Male non-offenders (*N*=102)	USA	Correctional facility	Go/No-Go Task	Lower conflict-related anterior cingulate cortex neural activity during Go/No-Go was associated with higher rate of commission errors and risk of re-arrest within a 4-year follow-up.
(Bilderbeck, Farias, Brazil, Jakobowitz, & Wikholm, 2013)	Male inmates (*N*=93); Female inmates (*N*=7)	United Kingdom	Correctional facility	Go/No-Go Task	Participants who completed a yoga course showed higher proportion of correct responses & more often correctly inhibited responses.
(C. Y. Chen et al., 2008)	Male impulsive-violent offenders (*N*=9); Male non-violent offenders (*N*=9)	Taiwan	Correctional facility	Go/No-Go/Stop Signal Task	Impulsive-violent group made fewer errors and had slower reaction times than controls.
(Dolan, 2012)	Male offenders with ASPD (low/medium/high pathology; *N*=96); Male healthy controls (*N*=49)	United Kingdom	Medium- and high-security forensic hospitals	Go/No-Go Task	Medium ASPD pathology group performed significantly worse than low pathology and controls; Low pathology group performed significantly worse than controls.
(Fine et al., 2016)	Male juvenile first-time offenders (*N*=930)	USA	Various	Go/No-Go Task	Go/No-Go response inhibition correlated with short-term (6 mo.) re-offending but not long-term (6-12 mo.) re-offending.
(Freeman et al., 2015)	High-psychopathy inmates (*N*=22); Low-psychopathy inmates (*N*=22)	USA	Correctional facility	Go/No-Go Task	No difference in error rate or reaction times between groups.

(Kiehl et al., 2000)	Male schizophrenic patients (*N*=12); Male psychopathic inmates (*N*=13); Non-psychopathic inmates (*N*=11)	Canada	Maximum-security correctional facility	Go/No-Go Task	No group differences in reaction times or percentage of inhibitory failures
(Maurer, Steele, Cope, et al., 2016)	Male incarcerated adolescents (*N*=100)	USA	Maximum-security juvenile detention centre	Go/No-Go Task	No correlation between task performance and psychopathic traits.
(Maurer, Steele, Edwards, et al., 2016)	Incarcerated female offenders (*N*=121)	USA	Medium-security correctional facility	Go/No-Go Task	Task performance not correlated with psychopathy or BPD symptomatology.
(Munro et al., 2007a)	Male violent offenders (*N*=15); Male prison staff (*N*=15)	Canada	Maximum-security correctional facility	Go/No-Go Task	Offenders made more commission errors than controls. Offenders had longer reaction times than controls.
(Ross & Hoaken, 2011)	First time federal inmates (*N*=56); Return federal inmates (*N*=37)	Canada	Medium-security correctional facility	Go/No-Go Task	Return inmates made more commission errors than first-time inmates.
(Schiffer & Vonlaufen, 2011)	Male non-sexual offenders (*N*=16); Male pedophilic child sexual offenders (*N*=19); Male non-pedophilic child sexual offenders (*N*=19); Controls (*N*=18)	Germany	Correctional facility	Go/No-Go Task	Both child sexual offender groups made significantly more errors on Go/No-Go task compared to healthy controls and non-sexual offenders.
(C.-Y. Chen,	Male impulsive-violent	Taiwan	Correctional	Flanker stop-	SSRT conflict score was larger in

Muggleton, & Chang, 2014b)	offenders (*N*=16); Male non-impulsive-violent offenders (*N*=16)		facility	signal task	impulsive-violent group than controls.
(Vilà-Balló et al., 2014)	Male juvenile violent offenders (*N*=17); Controls (*N*=17)	Spain	Correctional facility	Eriksen flanker stop-signal paradigm	Controls had a larger percentage of correct trials compared with offender group. Offenders had larger SSRT compared with controls.
(Schiffer et al., 2014)	Violent offenders with SUDs (*N*=21); Non-offenders with past SUDs (*N*=23)	Germany	Not specified	Stroop task	Offenders had a smaller Stroop effect (less difference in reaction time between congruent and incongruent trials) than non-offenders.
(Joyal et al., 2014)	Meta-analysis of studies on sex offenders, non-sex offenders, and general population	Various	Various	Stroop task	Across studies, sex offenders performed significantly worse than controls. Performance of sex offenders did not significantly differ from non-sex offenders.
(Kavanagh et al., 2010)	Male inmates (*N*=30); Male controls (*N*=58)	Australia	Correctional facility	Continuous Performance Task; Stroop task	Significantly more commission errors on Continuous Performance Task and Stroop task in offenders compared to controls.
(Meier et al., 2012)	Delinquent subjects with ADHD (*N*=13); Non-delinquent subjects with ADHD (*N*=13); Healthy controls (*N*=13)	Switzerland	Correctional facility	Continuous Performance Task	Both non-delinquent and delinquent subjects with ADHD had more omission errors, longer reaction time, and greater variability in reaction time compared with controls.

Abbreviations: ADHD = Attention deficit hyperactivity disorder; ASPD = Antisocial personality disorder; SSRT = Stop-signal reaction time; SUD = substance use disorder;

Table B2.

Summary of Studies Investigating Risk-Taking in Offender Samples

Study	Population	Country	Setting	Measures Used	Main Findings
(Brennan et al., 2010)	Weapon-using violent offenders (*N*=15); Non-weapon-using violent offenders (*N*=10); Nonviolent offenders (*N*=15)	United Kingdom	Correctional facility	Delay discounting task; Probability discounting task	No significant differences in discounting between groups. Weapon-using offenders made significantly riskier choices than non-weapon using offenders.
(Cherek et al., 1997)	Violent (*N*=9) and nonviolent (*N*=21) male parolees	USA	Laboratory	Delay discounting task	Violent parolees had significantly higher percentage of impulsive choices than the nonviolent parolees.
(Cherek & Lane, 1999)	Violent (*N*=10) and nonviolent (*N*=20) female parolees.	USA	Laboratory	Delay discounting task	Violent parolees had significantly higher percentage of impulsive choices than the nonviolent parolees.
(Hosking et al., 2017)	Male incarcerated offenders (*N*=49)	USA	Medium-security correctional facility	Delay discounting task	Significant positive relationship between total PCL-R score and subjective value-related neural activation in ventral striatum
(Jones et al., 2015)	Men (*N*=68) and women (*N*=12) entering Drug Court; University students (*N*=101)	United Kingdom	New South Wales Drug Court, UK	Delay discounting task	Drug court participants showed significantly higher discounting rates compared to university controls.
(Varghese et al., 2014)	Inmates within 5 months of release (*N*=146)	USA	Correctional facility	Delay discounting task	Discounting significantly associated with reactive criminal thinking, and also with number of previous incarcerations.
(Prehn et al., 2013)	Violent offenders with ASPD & emotional hyporeactivity (*N*=11); Violent offenders with	Germany	High-security forensic hospitals and prisons	Probability discounting-type task	No group differences in number of stock and bond choices; all participants more likely to choose low-risk bonds in trials with high uncertainty.

	ASPD & emotional hyperreactivity (*N*=12); Healthy controls (*N*=13)				
(Beszterczey et al., 2013)	Recently released recidivists (*N*=14) and non-recidivists (*N*=12); Controls (*N*=30)	USA	Offender re-entry service program	Iowa Gambling Task	No significant differences between groups.
(Yechiam et al., 2008)	Male and female offenders (*N*=81); Cocaine abusers (*N*=12); Patients with orbitofrontal brain lesions (*N*=21); Controls (*N*=32)	USA	Correctional facility	Iowa Gambling Task	Only healthy controls eventually learned to strongly prefer the advantageous decks. No significant differences between offenders grouped by type of crime.
(De Brito et al., 2013)	Violent offenders on probation with ASPD and psychopathy (*N*=17) and ASPD only (*N*=28); Healthy controls (*N*=21)	United Kingdom	Laboratory	Cambridge Gamble Task	Statistically significant differences between both ASPD groups compared to controls in terms of deliberation time and quality of decisions

Abbreviations: ASPD = Antisocial Personality Disorder;

Table B3.

Summary of Representative Neuroimaging Studies Examining Impulse Control in Offender Samples

Study	Population	Country	Setting	Measures Used	Neuroimaging Method	Main Findings
(Leutgeb et al., 2015)	Male high-risk violent offenders (*N*=40); Non-delinquent healthy controls (*N*=37)	Austria	Maximum-security correctional facility	N/A	Structural MRI	Offenders displayed less gray matter volume than controls in the prefrontal cortex and more gray matter volume in cerebellar regions and basal ganglia structures. Positive correlation between cerebellar volume and psychopathy/risk of recidivism. Amygdala and paralimbic area volumes correlated with risk of future violent crime.
(Tiihonen et al., 2008)	Persistently violent offenders with antisocial personality disorder and substance use disorder (*N*=26); Healthy men (*N*=25)	Finland	Forensic hospital	N/A	Structural MRI	Offenders had markedly larger white matter volumes in parietal, occipital, and cerebellar regions. Offenders exhibited gray matter atrophy in orbitofrontal cortex and postcentral gyrus. Larger volumes in posterior brain areas may reflect atypical neurodevelopment that underlies early-onset persistent antisocial and aggressive behavior.
(Aharoni et al., 2013)	Male offenders (*N*=96); Male non-offenders (*N*=102)	USA	Correctional facility	Go/No-Go Task	fMRI	Error-related brain activity during performance of the Go/No-Go task prospectively predicted subsequent rearrest among adult offenders within 4

						years of release. The odds that an offender with relatively low anterior cingulate cortex activity would be rearrested were approximately double that of an offender with high activity in this region.
(Freeman et al., 2015)	High-psychopathy inmates (*N*=22); Low-psychopathy inmates (*N*=22)	USA	Correctional facility	Go/No-Go Task	fMRI	High psychopathy inmates showed reduced deactivation of the brain's default mode network compared to the low psychopathy group.
(Fede et al., 2016)	Male inmates with SUD (*N*=131); Male inmates with no history of regular substance use (*N*=80)	USA	Correctional facility	Moral decision-making task	fMRI	When making decisions about controversial moral phrases, inmates with history of stimulant use showed less hemodynamic activity in the right amygdala relative to non-stimulant users.
(Geurts et al., 2016)	Psychopathic inmates (*N*=14); Healthy controls (*N*=20)	The Netherlands	High-security forensic psychiatric hospital	Monetary incentive delay task	fMRI	Functional connectivity between ventral striatum and dorsomedial prefrontal cortex was higher in psychopathic inmates compared to controls.
(Hosking et al., 2017)	Male incarcerated offenders (*N*=45)	USA	Medium-security correctional facility	Delay discounting task	fMRI; MRI	Psychopathy was associated with stronger subjective value-related activity within the nucleus accumbens during inter-temporal choice and with weaker intrinsic functional connectivity between nucleus accumbens and

						ventromedial prefrontal cortex. Weaker cortico-striatal regulation predicted more frequent criminal convictions. Data suggest that cortico-striatal circuit dysregulation drives maladaptive decision making in psychopathy.
(Prehn et al., 2013)	Violent criminal offenders with ASPD divided into emotional hyporeactivity (*N*=11) and emotional hyperreactivity (*N*=12); Noncriminal healthy controls (*N*=13)	Germany	High-security forensic hospitals and prisons	Probability discounting	fMRI	Emotionally hypo-reactive offenders, compared to healthy controls, had significantly diminished neural activation in the rostral anterior cingulate cortex in response to uncertainty as well as decreased activity in the prefrontal cortex when choosing “safe alternatives”.
(Shannon et al., 2011)	Incarcerated juveniles (*N*=107)	USA	High-security correctional facility	N/A	fMRI	Younger subjects tended to exhibit functional connectivity similar to the more-impulsive incarcerated juveniles, whereas older subjects exhibited a less-impulsive pattern; suggesting that impulsivity in the offenders may be a consequence of a delay in typical development.

(Maurer, Steele, Cope, et al., 2016)	Incarcerated adolescents (*N*=142)	USA	Maximum-security correctional facility	Go/No-Go Task	EEG	Psychopathy scores were negatively related to ERP mean amplitude. Antisocial traits were a significant predictor of reduced ERP amplitudes.
(Maurer, Steele, Edwards, et al., 2016)	Incarcerated female offenders (*N*=121)	USA	Medium-security correctional facility	Go/No-Go Task	EEG	Female psychopaths exhibited deficits in the neural correlates of post-error processing but not in error monitoring.
(Munro et al., 2007a)	Male violent offenders (*N*=15); Male prison staff (*N*=15)	Canada	Maximum-security correctional facility	Go/No-Go Task	EEG	Offender group produced smaller inhibitory ERP component amplitudes at frontal lobe sites.
(C.-Y. Chen et al., 2014b)	Male impulsive-violent offenders (*N*=16); Male non-impulsive-violent offenders (*N*=16)	Taiwan	Correctional facility	Flanker stop-signal task	EEG	Impulsive violent offenders and controls performed similarly in the stop-signal/flanker task, but showed differences in ERPs localized to anterior cingulate cortex.
(Vilà-Balló et al., 2014)	Male juvenile violent offenders (*N*=17); Controls (*N*=17)	Spain	Correctional facility	Erikson flanker stop-signal paradigm	EEG	Juvenile violent offenders exhibited deficits in error monitoring and inhibitory function as seen by a reduced amplitude of several inhibitory-related ERP components.

Abbreviations: EEG = electroencephalogram; ERP = event-related potential; fMRI = Functional Magnetic Resonance Imaging; MRI = Magnetic Resonance Imaging.

Table B4.

Summary of Recent Research on Technology-based Interventions for Addictions

*** Denotes Correctional Setting

Study	Population	Setting	Intervention Type	Main Findings
*** (Chaple et al., 2014)	Incarcerated offenders with SUD (*N*=494)	Correctional facilities	Computer-based psychosocial program entitled "Therapeutic Education System" (TES); control group received standard care	TES and standard care had similar session attendance rates and comparable gains in coping skills. Clients reported more favorable views of TES than of standard care.
*** (Chaple et al., 2016)	Incarcerated offenders with SUD (*N*=494) *same sample as Chaple et al. 2014	Correctional facilities	Computer-based psychosocial program entitled "Therapeutic Education System" (TES); control group received standard care	TES and standard care were equally effective in reducing re-incarceration, criminal activity, and substance use. TES may be useful in expanding access to treatment.
*** (Johnson et al., 2016)	Non-violent adult drug offenders (*N*=30)	Outpatient drug court program	A-CHESS: smartphone app containing information and tools, discussion boards, GPS-enabled high-risk location tool, and weekly survey; participants were also sent two text messages per day (motivational text and text promoting app usage)	Participants used the app on 62% days during the trial period. Social networking tools available through the app were the most commonly utilized. Clinical outcomes were not evaluated in this study.
(Brendryen et al., 2014)	Adult "at-risk" drinkers (*N*=244)	N/A	Internet-based multi-session alcohol intervention program entitled "Balance"; control group received single online session and online booklet about effects of alcohol	Intervention group drank average of 3 fewer drinks/week compared with control group at 6-month follow-up.
(Brown et al.,	Daily smokers	N/A	Interactive smoking cessation	StopAdvisor was more effective than control for

2014)	(*N*=4613)		website entitled "StopAdvisor"; control group received treatment via an information-only website	smokers of low but not high socioeconomic status.
(Campbell et al., 2014)	Addiction treatment outpatients (*N*=507)	Community-based outpatient treatment programs	Computer-based psychosocial program entitled "Therapeutic Education System" (TES); control group received treatment as usual	TES group had better retention than control group, and both groups had equivalent, high rates of abstinence for patients with a good prognosis at baseline. TES treatment doubled the odds of abstinence in patients with a poor prognosis at baseline. This effect was not maintained at 3 and 6month follow-ups.
(K. M. Carroll et al., 2008)	Adults with SUD (*N*=77)	Community-based outpatient substance use treatment provider	Computer-based training for CBT ("CBT4CBT"; teaches skills and strategies using quizzes and games); control group received treatment-as-usual	Intervention group submitted significantly fewer positive urine tests than control group. Treatment involvement and completion of homework significantly related to outcomes in intervention group.
(K. M. Carroll et al., 2014)	Cocaine-dependent individuals on methadone-maintenance therapy (*N*=101)	Methadone maintenance therapy clinics	Computer-based training for CBT ("CBT4CBT"; teaches skills and strategies using quizzes and games); control group received treatment-as-usual	Intervention group was significantly more likely to attain three or more consecutive weeks of abstinence from cocaine compared to control group. CBT4CBT showed continued benefit at 6-month follow-up.
(DeVito et al., 2018)	Cocaine-dependent individuals on methadone-maintenance therapy (*N*=79)	Methadone maintenance therapy clinics	Computer-based training for CBT ("CBT4CBT"; teaches skills and strategies using quizzes and games); control group received treatment-as-usual	Secondary analysis of sample from Carroll et al. (2014). Intervention group showed a trend toward greater reduction in Drug Stroop Effect (bias to drug-related cues) compared with control. Greater engagement in CBT4CBT was associated with greater reduction in Drug Stroop Effect.
(Dulin et al., 2014)	Adults with an alcohol use disorder (*N*=28)	N/A	"Location-Based Monitoring and Intervention for Alcohol Use Disorders" (LMBI-A):	Significant change in drinking quantity/frequency from baseline. The daily interview tool was rated most helpful. Change in drinking frequency was significantly

			smartphone app containing psychoeducation modules, craving and drink monitoring, daily interview tool, and GPS-enabled high-risk location tool	related to overall tool usage.
(Gonzalez & Dulin, 2015)	Adults with an alcohol use disorder (*N*=48)	N/A	"Location-Based Monitoring and Intervention for Alcohol Use Disorders" (LMBI-A): smartphone app containing psychoeducation modules, craving and drink monitoring, daily interview tool, and GPS-enabled high-risk location tool; control group received internet-based, brief motivational intervention supplemented with bibliotherapy	LBMI-A resulted in a significant increase in percent days abstinent (PDA) during the study, while control did not. Both interventions resulted in a significant decrease in percent heavy drinking days (PHDD) and drinks per week (PDW). However, the LBMI-A resulted in a larger decrease in the first 3 to 4 weeks after the study commenced than the control. Individuals reported less DPW and PHDD in weeks in which they reported greater LBMI-A usage.
(Guarino et al., 2016)	Opioid-dependent adults (*N*=160)	Methadone maintenance therapy clinic	Internet-based psychosocial program entitled "Therapeutic Education System"	Intervention was effective in improving treatment compliance and length of abstinence from opioids. Participants found it easy to use and helpful in managing drug cravings.
(Hoeppner et al., 2017)	Systematic review	N/A	Various	Review of apps concerning recovery and prevention of problematic alcohol use for the Android operating system. Apps included BAC calculators, apps offering information on risks of drinking and available treatment, tracking calendars, and apps offering support during intoxication. Apps were more popular if they were free and if personalized feedback was given. Tracking calendars, information provision apps, and motivational apps received higher user ratings.
(Kiluk et al., 2016)	Treatment-seeking	Outpatient substance	Computer-based training for CBT ("CBT4CBT"; teaches	Both CBT groups had better retention than TAU. There was an overall increase in abstinence and decrease in

	individuals with AUD (*N*=68)	abuse treatment facility	skills and strategies using quizzes and games); three conditions: (1) treatment-as-usual (TAU); (2) TAU + CBT4CBT; and (3) CBT4CBT + brief clinical monitoring	percent heavy drinking days during study period but more rapid reduction in drinking for TAU + CBC4CBT versus TAU only. At 6 month follow-up, similar effects across conditions.
(King et al., 2014)	Community opioid treatment program participants (*N*=59)	Substance abuse treatment centre	Internet-based video-conferencing via "eGetgoing"; control group received in-person counselling	Counselling attendance, treatment satisfaction, and ratings of therapeutic alliance were similar between groups. Three quarters of intervention group favoured internet-based counselling and rated it as more valuable than in-person counselling.
(Rooke, Copeland, Norberg, Hine, & McCambridge, 2013)	Adult cannabis users (*N*=225)	N/A	Internet-based, self-guided program for cannabis use disorder	Experimental group reported less cannabis use at 6 weeks, and less severe cannabis dependence symptoms at 3 months. Level of attrition was high however.

Abbreviations: AUD = Alcohol use disorder; CBT = Cognitive behavioral therapy; BAC = blood alcohol level