BEHAVIOURAL AND PHYSIOLOGICAL CORRELATES OF IMMERSION IN GAMBLING USING ELECTRONIC GAMING MACHINES

by

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Abstract

More than most gambling forms, Electronic Gaming Machines (EGMs, e.g. modern slot machines) have been linked to Gambling Disorder, a behavioural addiction recognized by the American Psychiatric Association. Immersion is a ‘trance-like’ state of extreme focus often reported in EGM gambling. Immersion in EGM gambling is a robust predictor of gambling problems, but is poorly understood. Few studies have investigated the cognitive, behavioural, and physiological correlates of this subjective state, and existing data rely on retrospective self-report. I investigated these topics, hypothesizing that immersion in EGM gambling produces measurable shifts in behaviour and physiological arousal, and that EGM immersion affects gamblers’ behaviour towards specific elements of the device.

The first two experiments recruited samples of undergraduate students, and examined whether self-reported immersion during an EGM gambling session correlated with cardiac markers of sympathetic and parasympathetic nervous system activity. EGM gambling saw decreased parasympathetic nervous system activity irrespective of immersion. Changes in sympathetic activity were limited to the first few minutes of gambling, and were specifically associated with immersion. Additionally, higher rates of immersion were found when participants placed bets across multiple paylines, a feature endemic to modern EGMs.

The third and fourth experiments recruited a sample of experienced EGM gamblers, who gambled on a real EGM while providing high-resolution eye tracking data. Immersion levels were associated with increased time spent looking at the EGM’s credit window, and decreased time on its spinning reels. Immersion was positively associated with the number of saccades participants made while gambling, as well as longer post-reinforcement pauses, a behavioural indicator of perceived reward value. We found that the EGM’s free spin bonus feature was

associated with significant increases in pupil diameter, potentially indicating sympathetic nervous system arousal.

Together, these experiments suggest that immersion is an active state characterized by increased reward-seeking. These data further link immersion to activity within the sympathetic nervous system, and show that immersion is impacted by specific features of modern EGMs. These results present novel candidate markers of immersion, both behavioural and physiological, and provide insight into the disproportionate rates of gambling problems associated with modern EGMs.

Lay Summary

Most people have at some point felt completely engrossed in an activity. Gamblers who experience this kind of *immersion* in slot machine use face an increased risk of developing gambling problems. However, it is unclear why this is. I conducted four experiments to better understand why slot machines seem to be so immersive, and how immersion in slot machine gambling is related to gamblers' feelings and behaviours.

I examined peoples' heart function and eye movements while they gambled on real slot machines in a laboratory. I found that immersion levels varied depending on the bet strategy that people used, and the parts of the game screen they had focused on. From their hearts and eyes, I found evidence linking immersion experiences to changes in physiological excitement levels at specific points during the gambling session. These results provide a clearer picture of how immersion relates to gambling products and problem gambling.

Preface

The experiment in Chapter 2 received approval from the UBC Behavioural Research Ethics Board (H14-02509). I designed this experiment, and collected these data using real slot machines housed in a laboratory at the Centre for Gambling Research at UBC. Analysis and drafting of the manuscript were completed by me. Luke Clark contributed to the experimental design and provided revisions on the manuscript prior to its publication. A version of Chapter 2 appears in the journal Addictive Behaviors:

Murch, W. S., & Clark, L. (2019). Effects of bet size and multi-line play on immersion and respiratory sinus arrhythmia during electronic gaming machine use. *Addictive Behaviors*. 88, 67-72. doi: 10.1016/j.addbeh.2018.08.014

The experiments in Chapter 3 received approval from the UBC Behavioural Research Ethics Board (H14-02509, H15-03434), as well as the UBC Biosafety Committee (B15-0221). The design of this experiment was outlined by me. This project involved the collection of impedance cardiography data in three separate experiments. I was responsible for one of these studies, Mario Ferrari was responsible for another, and Brooke McDonald for the third. Assistance in data collection was provided by Amit Chandna, Christopher de Groot, and Cameron Drury. We collected these data using real slot machines housed in a laboratory at the Centre for Gambling Research at UBC. Data processing responsibilities were shared by Brooke McDonald and I. Analyses were performed by me, with assistance from Mario Ferrari. I prepared the first-draft manuscript, to which all co-authors suggested revisions. A version of Chapter 3 appears in the journal Frontiers in Psychology:

Murch, W. S., Ferrari, M. A., McDonald, B. M., Clark, L. (2020). Investigating Flow States and Cardiac Pre-Ejection Period during Electronic Gaming Machine Use. *Frontiers in Psychology: Performance Science*. doi:10.3389/fpsyg.2020.00300.

The experiments in Chapters 4 and 5 received approval from the UBC Behavioural Research Ethics Board (H17-01181). I designed these experiments, and collected the data using real slot machines housed in a laboratory at the Centre for Gambling Research at UBC. Eye movement data processing was completed by me. Eve Limbrick-Oldfield, Mario Ferrari, and Kent MacDonald worked to create an algorithm that decomposes slot machine video recordings into time series data. Miriam Spering, Jolande Fooken, and Mariya Cherkasova provided guidance on working with eye movement and pupil response data. I completed the analyses with guidance by Eve Limbrick-Oldfield and Mariya Cherkasova. I prepared the manuscript, to which all co-authors provided significant input. A version of Chapter 4 appears in the journal Addiction:

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List of Abbreviations

AOI – Area of Interest

ADHD – Attention-Deficit Hyperactivity Disorder

ASRS – Adult ADHD Self-Report Scale

CPGI – Canadian Problem Gambling Index

DASS – Depression, Anxiety, and Stress Scale

DQ – Dissociation Questionnaire

ECG – Electrocardiogram

EGM – Electronic Gaming Machine

GEQ – Game Experience Questionnaire

GRCS – Gambling-Related Cognitions Scale

HR – Heart Rate

PEP – Pre-Ejection Period

PGSI – Problem Gambling Severity Index

PRP – Post-Reinforcement Pause, ΔPEP refers to task-related changes relative to baseline.

RSA – Respiratory Sinus Arrhythmia

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For ten years, I have been afforded the incredible privilege of living, working, and pursuing research on the traditional, ancestral, and unceded territory of the Musqueam people. Today, as much as the first time I set foot on the Lower Mainland, I am inspired and humbled by the beauty of this place, and by the collaborative spirit of the wonderful people I have met here.

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T + S

Chapter 1: Introduction

1.1 Addictive Substances and Behaviours

The experiments described in this document were carried out with the understanding that disordered gambling constitutes a form of addiction. However, as I will describe, the definition of addiction has undergone continuous revision since its inception, and especially in recent decades. To properly situate my experiments in context, I will first make the case that the current conception of addiction has made great strides towards understanding the negative consequences associated with both drugs of abuse and gambling.

To that end, Section 1.1.1 provides a brief account of historic shifts in the medical and popular definitions of addiction. By discussing de-emphasized criteria for defining substance use disorders, I will make the case that the currently-prevailing definition (which is broader in scope and less tinted by the exogenous effects of particular drugs), appropriately defines some behaviours as potentially addictive.

In section 1.1.2, I will outline the case for gambling addiction, and the burgeoning class of *behavioural addictions* more broadly. I will discuss Gambling Disorder, the first non-substance-related addictive disorder included in the Diagnostic and Statistical Manual for Mental Disorders (American Psychiatric Association, 2013). I will describe how the addictions field came to consider Gambling Disorder as the archetypal example of a behavioural addiction. This will be especially useful when interpreting attentional results for my experiments' involving experienced gamblers, who experienced differing levels of problem gambling (a subclinical designation denoting significant life harms resulting from gambling behaviour). In addition to shedding light on gambling activities, I assert that any effects observed in these experiments related to problem gambling are not simply explained by drug-related, exogenous chemical processes, and may therefore reveal novel insights into both addiction and attention.

1.1.1 Addictive Substances

Grains, rice, grapes, honey, tobacco, poppies, and coca leaves have been harvested in service of producing addictive substances for thousands of years (Blejer-Prieto, 1965; Cochrane, Chen, Conigrave, & Hao, 2003; Julyan & Dircksen, 2011; Musk & De Klerk, 2003; Sharma, Tripathi, & Pelto, 2010; Vallee, 1998). References to addictive substances are pervasive in artifacts from ancient times, but their prevalence in ancient societies is more often attributable to their medicinal or spiritual applications. Nevertheless, several clues point to the occurrence of addiction in ancient and medieval times. Historical figures and groups who had *ad libitum* access to addictive substances have often been known for behaviours consistent with addiction symptomatology, including drug tolerance and excessive or uncontrolled use. For example, both Alexander the Great (356 – 323 BC) and Ögedei Khan (1186 – 1241 AD) were known to be heavy drinkers with an exceptionally high tolerance for wine (Allsen, 2007; Cunha, 2004). Khan died following an evening of binge drinking and Alexander may have succumbed to alcoholic liver disease and acute withdrawal (though typhoid fever may be a more likely culprit). Andean cultures reportedly saw a precipitous rise in uncontrolled cocaine use following Pizarro’s conquest of Peru (1532 AD), when the previously-sacred plant was made available for mass consumption (Blejer-Prieto, 1965).

In the early 1800s, the prevalence of addiction – then called ‘inebriety’ – boomed in England and the United States, following a cultural shift away from beer and cider towards distilled liquors with greater alcohol content (Straussner & Attia, 2002; White, 1999). Inebriety was broadly understood as a characteristic inability to cease or deny alcohol use. Early pharmacotherapies and psychotherapies were attempted, but these efforts did little to stem the growing problem of substance use disorders in the western world. The establishment of "inebriate homes" emphasized non-medical, non-coercive means of treatment, and often framed sobriety as synonymous with Christian morality (Straussner & Attia, 2002; White, 1999). As a result, alcohol intoxication was increasingly rejected by American society, which saw the behaviour as stereotypic of the poor, or of immigrants from Ireland and Germany (Jaffe, 1978; Straussner & Attia, 2002).

This attitude would be short-lived; as American markets were soon awash with "patent medicines," over-the-counter cure-alls that were often adulterated with addictive substances. By the late 19th century, men, women, and children from all corners of American society were regularly consuming (and experiencing harms related to) alcohol, cocaine, and opiates (Grinspoon & Bakalar, 1981; Straussner & Attia, 2002). The term *addiction* gained favour around this time, derived from the Latin "addicere," which referred to the enslaving of an individual in service of one thing or another (Berridge & Mars, 2004; Nelson, Wallenstein Pearson, Sayers, & Glynn, 1982; Oxford, 1968). The harshness of this definition reflected an emerging pessimism towards the prospect of recovery that prevailed in the years leading up to the American prohibition era (Jaffe, 1978; Weiner & White, 2007; but see Rosenthal & Faris, 2018). No longer simply a moral defect that befell society's outgroups, addiction was increasingly regarded by experts as a pernicious disease that could strike anyone, perhaps incurably (Levine, 1978).

The first half of the 20th century in North America was marked by aggressive regulation and prohibition of addictive substances. The Pure Food and Drug act was passed in 1906, requiring drug manufacturers to disclose whether or not a given health product contained alcohol, opiates, cannabis, and other drugs of abuse. This crackdown effectively ended the patent medicine era, and heralded a new wave of federal intervention in the availability of addictive substances (Barkan, 1984). Around this time, the young field of psychology was dominated by the Behaviorist movement, which emphasized the observable, behavioural effects of different stimuli. Thorndike's influential *Law of Effect* (Thorndike, 1911) crystallized the Behaviorists' position, stating that behaviours which produce satisfactory outcomes are more likely to be repeated when the situation next appears. Thorndike argued that performed responses inherently strengthen an animals' connection to a particular situation, and "the greater the satisfaction, the greater the strengthening" (Beeler, 2012). The implications for this line of thinking are stark: drug use produces intense satisfaction that must therefore produce an intense strengthening of the likelihood to use drugs in the future. With no obvious mechanism to de-escalate habitual drug use, total avoidance of addictive substances seemed to be the only viable solution.

Yet, evidence began to accumulate by the middle 20th century that suggested the Law of Effect was not sufficient to explain addiction. In both a cohort study, and a 25-year longitudinal study of American veterans returning from the Vietnam War, a majority of people who experienced (typically) heroin addiction during wartime ceased problematic drug use without seeking formal treatment (Price, Risk, & Spitznagel, 2001; Robins, Davis, & Nurco, 1974). Within 12 months of returning home, 95% of soldiers who self-reported an addiction in Vietnam had successfully halted drug use (Robins et al., 1974). A separate review of alcohol, tobacco, and opiate research in mostly the 1960's and '70s showed the same pattern of cessation without formal treatment (Stall & Biernacki, 1986). These studies and others suggested that substance use and recovery can be moderated by the environmental, social, and psychological contexts in which they occur, dispelling the notion that drug use always increases the likelihood of future drug use. To be clear, modern conceptions of addiction may still fit well within a broader Behaviorist view (e.g. Lewis, 2018).

In 1964, addiction was defined by the World Health Organization in terms of *chemical dependence*: a pattern of compulsive drug taking, putatively resulting from the drug having become a physiological necessity (Berridge & Mars, 2004). If drug use ceased, medical consensus held that chemical dependence would induce a *withdrawal state* characterized by acute physical illness. A decade later, Solomon and Corbit attempted to explain chemical dependence in addiction, publishing the influential Opponent Process Theory of Motivation (Solomon & Corbit, 1974). In their model, addictive substances induce a euphoric response (α) that is later counteracted by a downregulation (β) of the body's production of the neurotransmitters involved. With repeated drug use, the theory argues that the positive response (α) is progressively weakened while the negative compensatory response (β) is progressively strengthened. As a result, drug use becomes increasingly focused on alleviating aversive states induced by earlier drug use. The β process may thus provide an explanation for withdrawal symptoms in periods of acute drug abstinence (Koob & Le Moal, 2005). This theory received some support. In one study, the self-reported 'rush' of smoking a cocaine paste was followed by low mood faster than could be explained by the still-relatively-high levels of the drug in participants' blood serum samples (Van Dyke & Byck, 1982).

However, the model could not account for apparent differences in the severity of withdrawal symptoms across different drugs. In terms of symptomatology, the withdrawal syndrome varies by substance (West & Gossop, 1994). Withdrawal from alcohol can be severe, and marked by sweating, tremors, and, seizures. Withdrawal from opioids can produce flu-like symptoms, including muscle aches and gastric troubles. Comparatively, withdrawal from cocaine

– a drug that is otherwise considered highly addictive – appears to be very mild, leading some authors to question its existence entirely (Lago & Kosten, 1994). When compared against other diagnostic criteria proposed in the Diagnostic and Statistical Manual of Mental Disorders, 4th edition (e.g. preoccupation with substance use, unsuccessful efforts to cut down substance use, etc.), the biomedical symptoms of drug withdrawal and tolerance to increasing doses were not so predictive of addiction as to suggest they were sufficient for diagnosis (Carroll, Rounsaville, & Bryant, 1994).

Together with the influence of social and psychological factors, the insufficiency of drug withdrawal to adequately diagnose addiction highlighted the need for an approach that allowed for a diverse, and flexible constellation of addiction symptoms. The definition of addiction that I will adopt for this dissertation holds that addiction is a disorder of mental health marked by: 1) considerable impairment in everyday functioning related to 2) compulsive seeking of either a consumable substance, or a specific activity such as gambling, 3) diminished control in limiting one's use of that substance or activity, 4) negative emotionality when the substance or activity is unavailable, and 5) chronic relapses following periods of abstinence (Koob & Le Moal, 2005). Notably, this contemporary definition avoids implying that addiction can only occur with exogenously administered chemicals. In other words, alongside drugs of abuse, many different behaviours could be potentially addictive.

1.1.2 Addictive Behaviours

Like substance-related addiction, potentially addictive behaviours received substantial attention in the late 20th and early 21st centuries. Much of this attention focused on one specific activity: gambling. "Compulsive gambling" behaviour was first described as a medical syndrome in a 1972 lecture by Robert Custer, a psychiatrist with Ohio Veterans Affairs (Korn, 2000). Interest in the topic grew through the 1970's. In 1980, clinically significant gambling problems first appeared in the DSM-III under the name "Pathological Gambling" in the category reserved for "Disorders of Impulse Control Not Elsewhere Classified" (American Psychiatric Association, 1980). In spite of its designation as an impulse control disorder, nearly all of the diagnostic criteria for Pathological Gambling were directly analogous to the diagnostic criteria for substance use disorders (Petry, 2006). In the years that followed, a substantial body of research contributed to a deeper understanding of Pathological Gambling, and assessed the appropriateness of both the name and category under which it appeared. In 2013, after considerable discussion, the American Psychiatric Association elected to move and rename Pathological Gambling in the DSM-V (American Psychiatric Association, 2013). The new condition, Gambling Disorder, appears as the only 'behavioural' addiction in a joint category called "Substance-Related and Addictive Disorders". The reasoning and evidence base underlying this shift has been discussed extensively elsewhere (Clark, 2014; Murch & Clark, 2016; Petry, 2006; Potenza, 2006), and I will not revisit these topics at length. In this section, I will give a very brief summary of the evidence linking Gambling Disorder to the broader class of substance-use disorders.

Individuals who experience Gambling Disorder are at increased risk of experiencing Substance Use Disorders. A large study comprised of 43,093 Americans found that the prevalence of Pathological Gambling was only 0.42% in the general population, but a majority pathological gamblers were experiencing a co-occurring alcohol use disorder (73.2%), or nicotine use disorder (60.4%), with a plurality (38.1%) experiencing a co-occurring drug use disorder (Petry, Stinson, & Grant, 2005). The study also found that mood (49.6%) and anxiety

(41.3%) disorders were highly comorbid with pathological gambling, lending credence to popular assertions that problem gambling behaviour is – at least partly – a learned response to ameliorate stress, low-mood, anxiety, or intrusive thoughts associated with past trauma (Dixon et al., 2018; Schüll, 2012; Szalavitz, 2016).

Gambling Disorder has a lot in common with Substance Use Disorders in terms of course, outcome, and frontline treatment techniques. The time of first exposure to both gambling and drugs of abuse usually occurs in adolescence or early adulthood among individuals who subsequently experience addiction (Petry, 2002). Like substance-related addictive disorders, Pathological Gambling may spontaneously remit (Hodgins & El-Guebaly, 2000). Among potential treatments for both Gambling Disorder and Substance Use Disorders, evidence supports the use of cognitive behavioural therapies, facilitated 12-Step programs, and motivational interviewing approaches (Hodgins, Currie, El-Guebaly, & Peden, 2004; Jonsson, Hodgins, Munck, & Carlbring, 2020; Marceaux & Melville, 2011; McHugh, Hearon, & Otto, 2010; Petry et al., 2006; Riper et al., 2014; Timko, DeBenedetti, & Billow, 2006). Pharmacological treatment using the opioid receptor antagonist Naltrexone has shown some promise of reducing cravings for, and the use of, addictive substances and gambling (Capurso, 2017; Grant, Kim, & Hartman, 2008; Krystal, Cramer, Krol, Kirk, & Rosenheck, 2001; Roche et al., 2017; Shufman et al., 1994).

The behavioural, physiological, and personality profile of Gambling Disorder is similar to that of Substance Use Disorders. Problem gamblers, like individuals who experience substance use problems, are more likely to experience attention-deficit hyperactivity disorder in childhood and adulthood (Rugle & Melamed, 1993; Waluk, Youssef, & Dowling, 2016). They are more likely to act without due forethought (trait impulsiveness), and to take greater risks in service of achieving stimulation (trait sensation seeking, see: Blaszczynski, Steel, & Mcconaghy, 1997; Clark, 2014). The cognitive profile of these groups shows marked similarities when it comes to undervaluing larger, later rewards compared to smaller, more immediate ones (Petry, 2001; Petry & Casarella, 1999), and overvaluing larger, infrequent rewards compared to smaller, more consistent ones (Brevers, Bechara, Cleeremans, & Noël, 2013). There is some prospective evidence to suggest that impulsiveness leads to addiction: children who showed undercontrolled temperaments at age 3 were at increased risk of Gambling Disorder and Substance Use Disorder at ages 21 and 32 (Slutske, Moffitt, Poulton, & Caspi, 2012).

These effects may be partly attributable to functional differences in the brains of individuals who experience these disorders, with a good deal of evidence implicating the ventromedial prefrontal cortex and ventral striatum (Murch & Clark, 2016; Volkow, Koob, & McLellan, 2016). Deeper still, several genetic variants have been associated with the risk of experiencing Gambling and Substance Use Disorders. A meta-analysis of family-based questionnaires and twin studies found significant increases in problem gambling risk for twins and siblings of problem gamblers as well as for family members more broadly (Walters, 2001). A large, single study of the Vietnam Era Twin Registry found that 12-20% of the genetic variation explaining Pathological Gambling expression was accounted for by individuals' risk for Alcohol Dependence (Slutske et al., 2000).

The recent history of addiction research can be accurately described as a period in which clinically significant problems with drug use and gambling underwent repeated conceptual revision, drawing closer together until eventually the determination was made to consider substance-related and non-substance-related addictive disorders jointly in the DSM-V. These trends were driven by: 1) an increasing emphasis on compulsive drug seeking and diminished control over drug use, 2) a decreasing emphasis on drug-dependent symptoms like withdrawal, and 3) increasing evidence of overlap in the mechanisms responsible for disordered gambling and disordered drug use. This new perspective presents a number of tools for investigating the neurocognitive basis of addiction. Since gambling does not by-itself involve the ingestion of an exogenous, chemical substance, problem gamblers without comorbid substance-use disorders represent a population whose addiction-related brain differences are arguably driven by endogenous mechanisms. Furthermore, gambling tasks being undertaken by problem gamblers can perhaps engage some of the same cognitive systems engaged during drug use, but in the absence of the drugs' confounding chemical properties.

The recognition that gambling represents an addictive product also presents a number of profound implications for gambling providers. Over the past 20 years, gambling operators have had to grapple with new questions about their role in supplying gambling activities. Do they, or should they, have a duty of care when it comes to providing and overseeing gambling activities? If so, how should problem gambling countermeasures be researched and applied? It is my hope that the experiments in this dissertation may thus reveal novel insights about the behavioural and physiological effects of other addictive behaviours, and perhaps addictive substances. In doing so, I hope to provide meaningful input to regulators seeking to create ethical and empirical gambling policies.

One final note before launching into the specific subject matter: the behavioural addictions perspective is not the only view on gambling to emerge in recent years. The topic of gambling has received increasing interest in the growing field of public health. One prominent example is the aptly-named Public Health Model (Korn & Shaffer, 1999), which highlights the interacting influences of individual factors, gambling devices, and gambling providers in the incidence of gambling harm. This model departs in several key ways from the influential Reno Model (Blaszczynski, Ladouceur, & Shaffer, 2004; Shaffer, Ladouceur, Blaszczynski, & Whyte, 2016), which suggests roles that gambling industry stakeholders might play in the ascertainment and application of so-called “responsible gambling” measures.

In contrast with the Reno Model, the public health approach to gambling emphasizes a broader spectrum of gambling-related *harms*, beyond the narrower set of symptoms used for diagnoses of Gambling Disorder (Korn & Shaffer, 1999; Wardle, Reith, Langham, & Rogers, 2019). Examples of gambling harms include negative impacts on significant others, and various manifestations of financial strain which can be long-lasting (e.g. poor credit rating years after gambling has ceased). Harms can also occur at broader levels of analysis, negatively impacting families, neighborhoods, cities, and nations. The model attempts to provide a more holistic analysis of the impacts of gambling, arguing that gamblers who do not reach clinical thresholds can nevertheless experience gambling-related harms, and that there may be no ‘safe’ level of gambling involvement (Markham, Young, & Doran, 2015). Given the high prevalence of these milder harm levels, the bulk of gambling-related harms may actually occur in individuals who would not meet clinical criteria for a diagnosis of Gambling Disorder (Canale, Vieno, & Griffiths, 2016).

Public health scholars point out that clinically-focused gambling research and theory (including the Reno Model) can place undue emphasis on gamblers’ individual responsibility in the development and prevention of Gambling Disorder (Hancock & Smith, 2017). While this assertion has been met with significant disagreement in the field (Shaffer, Blaszczynski, & Ladouceur, 2017; Young & Markham, 2017), the more comprehensive public health framework seems to present a reasonable, and moderate course of action (Abbott, 2020). Although the experiments in this dissertation focus on understanding one robust correlate of problem gambling, they recognize that the harms associated with gambling represent a broader class of gambling impacts that are dependent on individual, game-level, venue-level, and jurisdiction-level factors.

With respect to game-level factors, the gambling field has focused largely on one question: why do some gambling forms seems to be associated with higher rates of problem gambling and gambling harms (Binde, Romild, & Volberg, 2017; MacLaren, 2015)? In the next section, I will narrow my focus on Electronic Gaming Machines (EGMs, including modern slot machines), a high-speed gambling platform that is consistently associated with gambling problems.

1.2 Electronic Gaming Machines and Immersion Gambling

In the previous section, I discussed the burgeoning class of behavioural addictions, focusing on Gambling Disorder as the first addictive behaviour formally recognized in the DSM-5. Next, I will make the case that modern EGMs are the most problematic gambling form in most jurisdictions. In section 1.2.1, I will outline key technological changes in EGM design. I will argue that several key features of these games – and their interactions with gambler-level factors – are responsible for the greater levels of problem gambling often associated with these devices.

In section 1.2.2, I will discuss a special case of harmful interactions between gamblers and gambling devices (Korn & Shaffer, 1999): immersion in play. I will define immersion in the gambling context, and recount the different constructs that have been used to describe it. I will discuss its robust relationship with self-reported problem gambling, and outline the relative paucity of research on the cognitive underpinnings of the immersion phenomenon.

1.2.1 EGM Gambling

Gambling activities have become a ubiquitous part of life in Canada. Approximately 75% of Canadian residents engage in some form of gambling every year (MacLaren, 2015). In 2017, Canadians spent 17.3 billion dollars on gambling (Fantini & Diem, 2018), meaning that the average Canadian spent approximately $500 on gambling that year. But gambling was not always this prevalent. Gambling in Canada was limited to horse racing, until a 1969 amendment to the Canadian Criminal Code allowed for the establishment of large-scale lotteries as we know them today (Campbell, 2018). In 1985, a spate of innovations in digital and video gambling technology prompted the Canadian Government to officially transfer oversight of gambling to the provinces (Korn, 2000). Throughout the 1990s, gambling opportunities rapidly expanded, and gambling was soon accessible in casinos, smaller ‘community gaming centers’, and some provinces’ bars, pubs, and grocery stores. Government run gambling revenue has grown by more than 600% since 1992, when annual revenue was approximately 2.7 billion dollars (Korn, 2000).

However, these trends cannot be explained by gambling expansion alone. The 1990s also saw a global shift in preference for certain gambling forms among high-frequency gamblers. Between 2002 and 2012, 59.7% of gambling revenue was generated by EGMs, while the next largest product, lotteries, generated only 22.1% (MacLaren, 2015). This is surprising since the participation rate of EGM gambling (at most 20.3%) is much lower than that of lotteries (at least 69.6%) in the general public. Comparing the per-capita expenditure on EGMs to other forms paints a stark picture: the average EGM user in Canada from 2002 to 2012 spent between $1449.22 annually (the average spent on slot machines), and $2067.15 annually (the average spent on Video Lottery Terminals, VLTs, a multi-game device found in some provinces’ casinos and bars). In contrast, lotteries earned only $196.35 annually per capita. Given their profit-generating potential, it is perhaps no surprise that the number of EGMs in commission has risen sharply over the last 30 years (Schüll, 2012; Ziolkowski, 2011, 2015).

Proportionally higher rates of expenditure may be part of the reason that EGMs are disproportionately associated with gambling problems. Anecdotal accounts of the makeup of Gamblers Anonymous meetings have described a higher rate of EGM gamblers than would be expected by random chance alone (Schüll, 2012). A study of 44 treatment-seeking pathological gamblers found a significantly shorter duration of gambling activities prior to treatment-seeking among EGM gamblers (mean = 1.08 years), relative to users of other gambling forms (mean = 3.58 years; Breen & Zimmerman, 2002). This finding suggests that the onset of Gambling Disorder may be more rapid among EGM gamblers. The clearest evidence of a relationship between EGMs and gambling harm comes from a large Swedish study (Binde et al., 2017). In that study, 4,991 participants in the Swedish Longitudinal Gambling Study self-reported their rates of participation in various gambling activities, and the severity of problems they have experienced as a result of their gambling. The authors found an interaction between problem gambling and gambling participation such that – across most forms of gambling – individuals involved in multiple gambling activities were more likely to experience gambling problems. EGMs were the only gambling form to buck this trend; for EGM gamblers, participating only in EGM gambling was similarly associated with gambling problems to participating in five or more different gambling activities.

Perhaps the unique design of EGM devices offers some clues to explain their unique rates of profit and harm. Most EGMs look almost nothing like the all-analog ‘one-armed-bandits’ often portrayed in movies and on television; modern EGMs are typically a sophisticated digital gaming platform that is graphically more similar to contemporary video games (Schüll, 2012; se Box 1). This shift to a digital platform has enabled a tremendous expansion of the complexity of EGMs, introducing new features and audiovisuals that can be free-running or triggered by a diverse array of different in-game events. The effects of a number of these structural characteristics have been reviewed at length elsewhere (Barton et al., 2017; Murch & Clark, 2016). I will provide a brief summary of these efforts next.

Box 1: Modern, Multi-Line Slot Machines

Traditionally, a *slot machine* is a kind of analog, mechanical device with a large, side-mounted lever that – when pulled – spins three parallel drums bearing different symbols. If matching symbols on the drums happen to stop in a line across the center of the device, this kind of slot machine typically proceeds to dispense some number of coins into a trough mounted on its front. Over the last 30 years, these traditional devices have mostly been replaced by digital counterparts that more-closely resemble arcade video games (right). Although they still tend to appear in standalone cabinet enclosures, modern slot machines and other electronic gaming machines (EGMs) often employ video screens in place of real spinning drums, printed vouchers in place of coins, and less-fatiguing buttons in place of arms.

Migrating to a digital platform has also allowed EGM developers to program increasingly complex sounds, visuals, and bet strategies. Most modern EGMs can accommodate bets across dozens – or even hundreds – of different paylines spanning the device's video-simulated reels. Instead of lining up symbols across just the central row of the device's reels, gamblers can now place many concurrent bets to win payouts if symbols line up across the reels' top, bottom, diagonals, or in any number of different zig-zag configurations. This multi-line functionality creates a specific effect where the gambler may win on a single line (or a number of lines) but the size of that win does not cover the increased multi-line bet; these are called Losses Disguised as Wins (LDWs, see page 34). Whereas early slot machine gamblers were often limited to choosing between gambling on a 'penny' slot machine or gambling on a more-expensive, 'nickel' slot machine, modern EGM gamblers may choose to place hundreds of concurrent bets on each and every spin of these newer devices.

One distinct element of EGM design is the fact that gameplay is rapid, and provides frequent reinforcement. The ability to gamble quickly without requiring the intervention of a 3rd party (i.e. card dealers, lottery announcers, etc.) has always been a hallmark of EGM gambling, but these games' rate of reinforcement has been bolstered by the invention of multi-line gambling (Templeton, Dixon, Harrigan, & Fugelsang, 2015). Multi-line EGMs (see Box 1) allow gamblers to place bets along the middle of the spinning reels as usual, but also along the top of the reels, the bottom, diagonally, and along various different zig-zag patterns. This approach distributes the total denomination of a given bet amount across multiple smaller bets, increasing the likelihood of receiving at least one winning combination of symbols, and decreasing the size of the payout for any given win. Multi-line EGM gambling thus leads to a 'smoother' gambling experience with shorter losing streaks and smaller, more frequent reinforcement (Schüll, 2012).

Frequent reinforcement may be key to encouraging continued gambling, as gambling activities employ variable ratio reinforcement schedules (Skinner, 1953). A functional neuroimaging study using a card selection task with monetary rewards found significant increases in the release of the neurotransmitter dopamine among healthy volunteers in a variable ratio reinforcement condition, compared to those in a fixed ratio condition (Zald et al., 2004). The large body of research showing interrelations between dopamine signaling, risky decision-making, and addiction has been described in depth elsewhere (Murch & Clark, 2016; Volkow & Fowler, 2002). For these purposes, it is sufficient to recall that dopamine supports Pavlovian conditioning in reward learning tasks (Schultz, 1997). Zald and colleagues' results thus suggest that this neural marker of reward signaling increases with greater uncertainty. These effects may be compounded by the finding that tonic dopamine levels increase as uncertain rewards approach perfect (i.e. 50-50) uncertainty (Fiorillo, Tobler, & Schultz, 2003). It is therefore fair to speculate that modern EGMs, which provide frequent – but unpredictable – reinforcement produce greater activation of reward-sensitive brain regions than older EGMs that provide less-frequent rewards, or (for example) lotteries which provide highly-infrequent rewards.

A second structural characteristic found in modern, multi-line EGMs is known as a *Loss-Disguised-as-a-Win* (Dixon, Harrigan, Sandhu, Collins, & Fugelsang, 2010). As a result of placing many concurrent bets across multiple paylines, multi-line EGM gamblers frequently encounter winning outcomes that are ultimately smaller in size than the overall wager they had placed. In spite of the net loss of funds, the EGM treats these outcomes as if they represent real wins, producing win-related audiovisuals for the gambler. These audiovisuals may mislead gamblers into erroneously believing that they are receiving more monetary reinforcement than actually occurred: a recent review found that EGMs containing LDWs were associated with systematic overestimates of the number of times gamblers had won (Barton et al., 2017).

Near misses represent a structural feature of gambling games that – while not unique to EGMs – are highly salient and seem to impact gamblers' beliefs and actions. A near miss is any unpredictable outcome where positive reinforcement was almost obtained, but was narrowly thwarted (e.g. lining up two of three jackpot symbols on an EGM, or having a lottery ticket that reads 1, 6, 18, 20, 30, 38, and 42, when the winning numbers are 2, 7, 19, 21, 31, 39, and 43). A moderate presence of near misses in EGMs has been seen to encourage persistence in gambling (Côté, Caron, Aubert, Desrochers, & Ladouceur, 2003; Kassinove & Schare, 2001). These outcomes seem to induce physiological arousal, a sense of frustration, and an eagerness to continue gambling (Barton et al., 2017; Murch & Clark, 2016). In a simulated EGM task, near misses were also found to activate brain regions that are similarly recruited during jackpot wins (Clark, Lawrence, Astley-Jones, & Gray, 2009).

Thus, a number of EGM structural features have been associated with distorted gambling beliefs, changes in neurochemical processes associated with decision-making under risk, and increasingly risky behaviours. It is clear that aspects of EGM design may – at least partially – account for the disproportionate association between EGMs and problem gambling. A further element of EGMs that appears associated with gambling harm concerns their ability to produce a strong sense of *immersion in play* among at-risk gamblers. This distorted state of cognition is a central element of the experiments in this dissertation, and is the central topic of the next subsection.

1.2.2 "Immersed in the Slot Machine Zone"

> "Gamblers know how a man can sit for almost twenty-four hours…
> without looking to right, or to left."
>
> -Dostoyevsky, "The Gambler", 1867

In their influential Public Health Model of gambling, Korn and Shaffer (1999) argue that complex interactions between individual factors (e.g. genetic risk factors, trait impulsiveness), environmental factors (e.g. gambling accessibility, gambling advertising), and the structural characteristics of specific gambling forms "can produce a range of possible adverse outcomes". *Immersion* in EGM gambling represents one example of a 'player-product interaction', wherein the traits of modern EGMs can combine with the traits of vulnerable gamblers to produce a strong sense of absorption in gameplay. As I will describe next, this interaction seems common in EGM gambling, and appears to be robustly linked to individuals' problem gambling symptoms. However, despite these trends, little research has been done to characterize the nature of this phenomena, its causes, or its correlates within gambling situations.

Research interest in EGM immersion began soon after Pathological Gambling first appeared in the DSM-III. In 1980, Durand Jacobs began pursuing a novel organizing framework that he later called "The General Theory of Addictions," (Jacobs, 1986). Jacobs placed the primary emphasis of his framework on two predisposing factors that he hypothesized were present in all cases of addiction: 1) a chronic, unpleasant physiological state of hypo- or hyper-arousal, and 2) a deep-seated sense of rejection by others, rooted in childhood or adolescence. Remarkably, while Jacobs argued that addiction could occur across a pantheon of common products including illicit drugs, prescription medicines, food, and behaviours, he adopted *gambling* as the prototypical addictive product. He would go on to argue that all addictive products elicit a common set of "dissociation-like" experiences among users experiencing addiction (Jacobs, 1988). These experiences included feelings of being "in a trance", taking on "a different identity", being "outside of oneself" or "watching oneself", and experiencing "memory blackouts" while engaged with one's preferred addictive product. Jacobs tested these claims in large samples of older adults and adolescents, finding that problem gamblers, alcohol users, and overeaters were more likely than healthy comparison groups to endorse having these experiences while consuming these problem-causing products. These findings spurred many follow-up investigations, with particular emphasis on 'dissociative' experiences among gamblers.

Before I proceed in describing the empirical data, however, I would like to discuss a difference in preferred terminology when researching these experiences. Although the term 'dissociation' was adopted early on, and has been maintained by several researchers examining the phenomenon, the field of dissociation research encompasses a much broader range of normative and clinically-significant experiences (Butler, 2006). It may be the case that some symptoms (e.g. depersonalization) occur in dissociation associated with Post-Traumatic Stress Disorder (e.g. Steuwe, Lanius, & Frewen, 2012), but are relatively less common in EGM immersion. Researchers who prefer the term acknowledge that each of the broader dissociative experiences listed above does not necessarily apply in the case of EGM immersion (Schluter & Hodgins, 2019). Still, broadening the dissociation concept to fit this purpose may not be warranted without substantial evidence to suggest that its use is appropriate in this case.

Other authors have chosen to adopt the term “dark flow”, borrowed from the Flow field in positive psychology (Csikszentmihalyi, 2014; Dixon et al., 2018). Flow theory posits a unique mental state of total involvement that can occur when one is actively engaged in a well-practiced and interesting activity (Csikszentmihalyi, 2014). Flow is argued to occur when there is a good balance between the high cognitive demands of a task, and the high degree of skill an agent mobilizes to perform it. The resulting experience is purportedly marked by 1) high attention to the activity, 2) a sense of intrinsic reward applied to the activity, and 3) decreased metacognition and awareness of task-irrelevant stimuli. Proponents of the term (e.g. Dixon et al., 2018) argue that this absorptive phenomenon in EGM use constitutes a “flow-like” state that has distinctly negative (or ‘dark’) long term consequences (problems at work and at home, mounting financial losses, etc.). However, the applicability of flow theory to EGM immersion is still largely unknown.

Still others have referred to an “altered state of consciousness” (McKeith, Rock, & Clark, 2017; Tricker, Rock, & Clark, 2016) and “the slot machine zone” (Oakes, Pols, Lawn, & Battersby, 2018; Schüll, 2012) in describing the phenomenon. The former is, in my view, too broad to provide much indication of what the authors believe is occurring. The latter term is not preferred here because it implies that the experience is somehow specific to slot machines. For these reasons, I have avoided both of these terms.

In conducting my dissertation research, I initially chose to use the term "immersion", because I feel it accurately captures these aspects of the experience without implying a broader range of dissociative experiences. It similarly avoids implying a universally negative or 'dark' experience (in lieu of empirical support for such a claim), or implying that the experience is solely caused by slot machines. Please also note that, through the course of these experiments, I have found evidence to support the "flow" framework in reference to EGM immersion (e.g. Chapter 4). Thus, this term has been adopted for later publications (e.g. Chapter 3). Despite our differing terminology, authors investigating this topic are generally agreed that this state involves: 1) some alteration of normal attentional processes, 2) a subjective feeling of increased involvement in the task, and 3) a sense that one is ignoring, escaping or forgetting about stimuli and events beyond the gambling activity. As a result, I and the gambling field generally treat these terms as interchangeable when referring to absorptive experiences in EGM gambling.

Returning now to the influential theory of dissociation in addictive activities: Jacobs' initial findings have been supported in a variety of samples and gambling situations, and using a number of conceptually similar instruments. A study of 57 pathological gamblers and 115 healthy control participants found that the pathological gamblers were more likely to endorse feeling "so involved [in gambling] that they lose all notion of time and space" (Martínez-Pina et al., 1991). A large-scale survey of high school students in Quebec found similar differences between problem gamblers and non-problem gamblers using Jacobs' four-item Dissociation Questionnaire (DQ): students at risk of gambling problems were significantly more likely to report having these experiences at least once while gambling (Gupta & Derevensky, 1998). Several other experiments of undergraduate students, experienced gamblers, and problem gamblers have found significant correlations between problem gambling severity and DQ score. In some cases, this association referred to lifetime experiences of gambling immersion (Cartmill, Slatter, & Wilkie, 2015; Hopley & Nicki, 2010; Wanner, Ladouceur, Auclair, & Vitaro, 2006), and in others it referred to state-related immersion self-reports following a laboratory-based EGM gambling session (Murch, Chu, & Clark, 2017). Most research on immersion has been in the context of EGM use, and gambling immersion may be especially common in EGM use: an Australian survey that asked gamblers if they had ever felt “in a trance” while gambling found that 76% of affirmative respondents had been gambling on an EGM at the time (Office for Problem Gambling, 2006).

Broader effects were observed in a smaller sample of adult pathological EGM gamblers, who were more likely to report generalized dissociative experiences on the Dissociative Experiences Scale (Bernstein & Putnam, 1986), as well as some items from the DQ (Diskin & Hodgins, 1999). The authors of that study found further success in integrating a fifth item into Jacobs’ dissociation-like gambling experiences: the tendency to feel as though one loses track of time while immersed in EGM use. The association they found between problem gambling severity and propensity for generalized dissociation has also been replicated (Gori et al., 2016).

The origins of the robust association between gambling immersion and problem gambling risk have been the subject of several investigations. A prominent etiological model of disordered gambling argues that the driving motivation among many gamblers in a major pathway into problem gambling is the urge to escape from comorbid anxiety, depression, or stressful thoughts relating to past trauma (Blaszczynski & Nower, 2002). This would explain why dissociative experiences among gamblers may occur outside of gambling situations as well. A number of researchers have investigated the possibility that immersion in gambling provides a cognitive escape from these negative states. This interpretation is similar to that of withdrawal-based accounts of Substance Use Disorders described in section 1.1.1, insofar as negative reinforcement forms a key mechanism underlying continued gambling. A study of 190 EGM gamblers in Australia found that self-reported “need to escape” accounted for 46% of the variance in problem gambling severity (McCormick, Delfabbro, & Denson, 2012). An Australian survey of land-based (i.e. non-online) gamblers found significant relationships between problem gambling, self-reported anxiety, and gambling immersion (Cartmill et al., 2015). A relatively large sample of casino patrons who participated in a realistic simulated EGM experiment found significant relationships between problem gambling risk, gambling immersion (measured using the Game Experience Questionnaire Flow Subscale; IJsselsteijn, de Kort, & Poels, 2013), and past-week depression symptomatology (Dixon et al., 2018). Further investigations have since replicated the effect (Dixon, Gutierrez, Larche, et al., 2019).

Immersion in gambling activities has been called “dissociation”, “dark flow”, and “the slot machine zone”. In all cases, these terms refer to feeling as though one is “in a trance” while gambling, losing track of time, and forgetting about things going on around them. Across a variety of instruments and scenarios, immersion in gambling appears to be positively related to problem gambling. Some evidence suggests that this relationship may be mediated by gamblers’ motivation to escape pre-existing depression or anxiety symptomatology, but relatively little is known about the state itself. What *is* immersion? What happens during immersion that makes it appealing to individuals experiencing negative cognitions or those at risk of gambling problems?

1.3 Attention during gambling

Thus far, I have spoken quite broadly about psychological phenomena, discussing behavioural addiction and EGM immersion as observed in the complex behaviours and fully-formed beliefs of adult research participants. In this section, I will argue that the decision to gamble is influenced by perceptual outputs, selective attention, and the moderating effects that prior experience can have on these processes. I will review attentional experiments from the broader substance use literature, drawing parallels with gambling. I will argue that experiences of immersion while gambling may represent a special case of cue-sensitized attention.

Perceptual and attentional processes govern our interactions with the world, and are potentially important factors in the development and maintenance of gambling behaviour. Before any gambling can occur, a would-be gambler must first comprehend that there is an opportunity to gamble by (for example) perceiving an EGM or a display case containing scratch-off lottery tickets. To this end, gambling providers employ a litany of attractive signals including flashing lights, bright colours, and imagery associated with common hobbies, celebrities, or desirable goods like cars, mansions, and money. These visual signals likely play an important role in potentiating engagement with gambling activities. Low-level visual properties like saturated colours and flashing lights can attract eye movements, and can in some cases be efficiently located when visually-searching complex scenes (Ware, 2012). Highly-salient visual features may increase the likelihood that gambling stimuli will be bound and held in conscious awareness via selective attention (Rensink, 2015; Treisman & Souther, 1985). Though it has not been empirically examined, the decision to initiate gambling likely depends – at least in part – on these activities' ability to leverage low-level perceptual and attentional processes. However, perceiving a gambling opportunity is only the first hurdle. A flashing light on top of an EGM may be adept at drawing eye movements, but its presence may be quickly habituated unless it signals something important or personally relevant (Mather, 2007). Where basic visual features make use of stimulus-driven perceptual processes, more complex symbols and images may leverage past learning, perhaps imbuing the gambling activity with previously-learned, positive associations. Once again, however, these specific hypotheses have not been empirically tested.

The more immediate question posed by these considerations is how perceptual and attentional processes could possibly account for the extreme experiences reported by problem gamblers during EGM immersion. Qualitative evidence suggests that EGM immersion can be a highly absorptive experience, obscuring gamblers' senses of time passing, upcoming appointments, physical needs like eating and urination, and attention to any visual stimulus outside the game (Jacobs, 1986; Oakes et al., 2018; Schüll, 2012). In one extreme case, a gambler failed to notice that another patron seated nearby had suffered a heart-attack, and continued gambling, unabated, as paramedics rushed by to begin treatment (Schüll, 2012). At the same time, these devices do not seem to possess an inherently-overwhelming appeal; participation in casino gambling is typically much less prevalent in the general population than participation in lottery gambling (Malatest, 2014; Office for Problem Gambling, 2006). Convenience-sampled undergraduate participants in my earlier studies sometimes remarked that EGM use was neither exciting, nor particularly positive (Murch et al., 2017). Assuming that the qualitative evidence above is supported empirically, how could exposure to the same stimulus, an EGM, come to produce such drastically different outcomes in different people? What effects does EGM use have on attentional selection for EGM-associated stimuli, and how do these effects change as use frequency escalates towards problematic levels? Unfortunately, relatively few investigations of EGM use have sought to examine attentional processes, and fewer have specifically examined the effects of EGM immersion on attention. I will recount them next.

1.3.1 Attention to EGM Gambling

Around the turn of the century, Diskin and Hodgins (1999) published an influential pilot study that sought to investigate gamblers' attentional states during EGM use. Though small, encompassing only 23 participants, this experiment has been highly influential in the field, spurring a considerable amount of follow-up research and inspiring many of the experiments described in this dissertation. Following Jacobs' (1986) General Theory of Addictions, Diskin and Hodgins hypothesized that if EGMs were capable of producing feelings of dissociation and extreme focus on gameplay (as Jacobs argued), these effects should be quantifiable using behavioural measures of attention to stimuli existing outside the game. They adopted the term "attentional narrowing" as shorthand for the prediction that allocating substantial attention to the game leaves fewer attentional resources free to monitor the visual area peripheral to the game. They hypothesized that these effects would be more pronounced in a group of problem EGM gamblers, as compared to EGM users who gamble only occasionally. To test these hypotheses, they affixed four small lights on the ends of arms mounted 9.5 inches outside the four corners of the game screen. Every few seconds during play, one of the four lights would illuminate, prompting a button press to acknowledge that the light had been seen. As hypothesized, participants in the problem gambling group were significantly slower to respond to the light response task while gambling on the EGM. Problem EGM gamblers provided responses that were more than 20% slower on average (problem gambling mean response time = 950.2 ms, occasional gambler mean = 729.4 ms), and were significantly more likely to endorse feeling as though they “lost track of time,” and “were in a trance” while gambling. These results are consistent with an attentional narrowing mechanism during problematic EGM use: attentional resources normally devoted to passively monitoring peripheral visual space and the passage of time may have been diverted to instead devote additional attention to the EGM.

A key limitation of Diskin and Hodgins’ original design is that their illumination response dual task required participants to provide 45 responses in a task that only took three minutes. Although their results provided support for the hypothesis that problem gambling interferes with peripheral attention, it may also be the case that the very short session and frequent interruptions prevented participants from experiencing a typical level of immersion or dissociation in play. For my MA project, I therefore conducted a conceptual replication of Diskin and Hodgins’ attentional narrowing effect using a much longer EGM gambling session and fewer probe trials on the target detection dual task (Murch et al., 2017). In these experiments, samples of experienced EGM gamblers and undergraduate students gambled on a real EGM for 30 minutes. The game was flanked by two vertical projection screens onto which I presented a constant stream of irrelevant distractor shapes (white circles). The shapes appeared at the outer edges of the screens and moved at a constant rate towards the game, disappearing just before reaching the EGM. Fifteen times during the task, the distractor was replaced by a target shape (red squares), prompting a button press response.

In my sample of experienced EGM gamblers, I found that the level of past-year, self-reported gambling problems significantly predicted the number of target shape responses provided while gambling. I also found that Diskin and Hodgins’ variant of the Jacobs Dissociation Questionnaire significantly correlated with self-reported problem gambling. These results are consistent with those of Diskin and Hodgins (1999), and again suggest that problem gamblers may experience dissociation-like immersion in gambling, as well as deficits in gambling-irrelevant attention during EGM use. Crucially, however, a control group in this study found that participants reported significantly higher scores on the Dissociation Questionnaire when the target-detection task was absent. Though my results were consistent with Diskin and Hodgins', the validity of both studies' attempts to recreate a typical gambling experience may have been diminished by the inclusion of target-detection tasks.

Though these experiments have provided some support for the hypothesis that attention to the visual world beyond an EGM may be diminished among at-risk gamblers, they could not provide any indication of the degree of attention paid to the device itself. This is a crucial distinction, as other scholars would propose a mechanism for EGM immersion rooted primarily in negative reinforcement (Dixon et al., 2018; Schüll, 2012). Discussed in depth in my introduction to chapter 4, the negative reinforcement account posits that cognitive escape from pre-existing symptoms of stress or low mood is the key driver of EGM immersion experiences. Though Schüll had not obviously intended to provide an alternative to the attentional narrowing account, their interpretation raises the alternative explanation that visual attention may be diminished globally, rather than focused on the EGM. In other words, the relief from stress or low mood provided by EGM use may be tranquilizing to the extent that gamblers are generally less vigilant towards external stimuli. In later chapters, I will refer to the attentional narrowing account as "zoning in" on EGM use, and the negative reinforcement account as "zoning out".

A number of other attempts have been made to examine aspects of attention during gambling, and attention to gambling-related stimuli. In spite of their varying neurochemical effects, many drugs of abuse produce similar shifts in cued attention. Users of alcohol, cannabis, nicotine, opiates, and cocaine have all shown similar attentional biases towards drug-related stimuli, at the expense of processing speed for non-drug stimuli (M. Field & Cox, 2008; M. Field, Munafò, & Franken, 2009). Crucially, concordant effects have been observed in problem gamblers, suggesting that these attentional biases are the result of an endogenous process, and not an exogenous drug effect (Honsi, Mentzoni, Molde, & Pallesen, 2013). One study of these attentional biases in gamblers employed eye tracking, showing that problem gamblers were faster than healthy control participants to direct eye movements toward gambling-related imagery (Brevers et al., 2011). Further, the problem gambling group was significantly faster to detect changes in gambling-related images, and significantly slower to detect changes in non-gambling images. These findings support the hypothesis that gambling activities, like other addictive products, elicit biases in visual attention among those who experience harm associated with their use.

Recently, McGrath and colleagues (2018) clarified these effects, finding that attentional biases to gambling stimuli were largely specific to gamblers' preferred gambling form. In their study, groups of EGM users, poker players, and healthy controls passively viewed gambling and non-gambling images. The greatest amount of time spent fixating on EGM images was observed among the EGM gambler group, and the greatest time spent fixating on poker imagery was observed among the poker group. The control group spent significantly less time fixating on both poker and EGM images, and all three groups spent relatively little time looking at bingo related imagery (a third game, with which no group was very experienced). Extrapolating from these findings, it seems plausible that attentional narrowing could occur among experienced EGM gamblers simply because cues of a preferred gambling form can attract increased attention.

Nevertheless, my conclusions that dual-task behavioural paradigms could not provide sufficient insight into overt visual attention during EGM gambling, and that their introduction may in fact significantly diminish the experience of EGM immersion, led me to explore less invasive, more direct indicators of attentional processes during gambling activities. I pursued two general approaches that were likely to be more informative, and less disruptive than behavioural dual tasks. The first approach was explored with the hope of innovating new methods for observing granular gambling behaviours, and involved collecting a large corpus of eye tracking data while experienced EGM gamblers used a genuine EGM (detailed in Chapter 4). Eye tracking data for each participant was synchronized with gameplay data extracted from the EGM, providing the first in-depth look at gamblers' overt visual attention to different parts of the game at multiple different timepoints within each gamble. From this data, we investigated potential links between participants' gameplay behaviours and self-reported EGM immersion. The second approach relied on a large body of psychophysiological evidence demonstrating correlations between the activity of physiological subsystems, and affective or cognitive states (Blascovich & Mendes, 2010; Cacioppo, Tassinary, & Berntson, 2007; Kreibig, 2010). Prior psychophysiological investigations of gambling phenomena will be discussed in the next subsection.

1.4 Physiological Responses to Gambling Activities

In the previous subsection, I made the case that EGM immersion represents a clinically significant departure from normal attentional processing that is disproportionately observed among gamblers at risk of experiencing gambling problems. I further argued that, in order to understand the phenomenon, the gambling field needs indicators of EGM immersion other than subjective self-reports on one's own attentional state. In this subsection, I will make the case that gambling researchers have made a number of important contributions using psychophysiological measures, and that psychophysiological tools have the potential to provide further insights into EGM immersion.

The hypothesis that has received the most attention with respect to physiological responses to gambling concerns the broad, somatic effects of gambling activities. Gambling activities have often be portrayed as exciting, elating, or thrilling in popular culture (Monaghan & Derevensky, 2008; Turner, Fritz, & Zangeneh, 2007). Though it seems pedestrian in a society awash in the idea that gambling is an exciting thing to do, the extent to which gambling activities increase activity within the sympathetic nervous system was (and remains) an empirical question. Over the past 40 years, this hypothesis has been tested repeatedly, using a number of sample populations, gambling activities and environments. Most of these reports examine changes in participants' heart rates, measured as beats per minute (BPM). Under most circumstances, gambling situations have been associated with some degree of increase in participants' BPM; significant heart rate increases have been observed for blackjack (Anderson & Brown, 1984; Meyer et al., 2000), horse-racing (Coventry & Norman, 1997; Wulfert, Roland, Hartley, Wang, & Franco, 2005), and EGMs (Coventry & Constable, 1999; Coventry & Hudson, 2001; Griffiths, 1993). However, these effects are sensitive to a number of extraneous factors, including whether the experiment took place in a real gambling venue or in a laboratory (Anderson & Brown, 1984; S. H. Stewart, McWilliams, Blackburn, & Klein, 2002; Yucha, Bernhard, & Prato, 2007), whether real monetary rewards were offered (Wulfert et al., 2005), whether the participant experienced a number of wins (Coventry & Constable, 1999; Coventry & Hudson, 2001; Dixon, Collins, Harrigan, Graydon, & Fugelsang, 2015; Dixon et al., 2010), or whether auditory features of the game had been muted (Dixon, Harrigan, et al., 2014). In some cases, and perhaps due to some of these moderating factors, some researchers have not found any significant effects of gambling activities on heart rate measures (Diskin & Hodgins, 2003; Murch et al., 2017; Yucha et al., 2007). Crucially, despite numerous investigations, gambling-related changes in heart rate do not seem to be affected by problem gambling (Diskin & Hodgins, 2003; Dixon, MacLaren, Jarick, Fugelsang, & Harrigan, 2013; Murch et al., 2017).

Gambling research on heart rate has been supported by research examining skin conductance levels during gambling activities. Scholars have reported significant increases in skin conductance following EGM wins and near-misses, and losses-disguised-as-wins, compared to unambiguous losses (Clark, Crooks, Clarke, Aitken, & Dunn, 2012; Dixon, Harrigan, Jarick, Fugelsang, & Sheepy, 2011; Dixon et al., 2010, 2013; Porchet et al., 2013). In other words, the presence or promise of reinforcement in gambling tasks has been associated with increased activation of the sympathetic nervous system. Interestingly this effect appears to be blunted among individuals who report experiencing gambling problems (Lole & Gonsalvez, 2017; Lole, Gonsalvez, Barry, & Blaszczynski, 2014). Skin conductance level has a key advantage over heart rate metrics because the electrodermal responses (increases in the conductivity of skin surfaces as a result of perspiration) appear to be primarily mediated by activation of the sympathetic nervous system, whereas heart rate is considerably dependent on the dual influences of both the sympathetic and parasympathetic nervous systems (Cacioppo et al., 2007). Observing changes in BPM from baseline could show significant increases as a result of either sympathetic nervous system activation, or decreases in parasympathetic tone.

In an earlier study, I attempted to separate parasympathetic tone from heart rate metrics during an EGM gambling session (Murch et al., 2017). I used a marker of cardiac parasympathetic tone called Respiratory Sinus Arrhythmia (RSA). RSA quantifies components of the variance between successive heart beats, providing an indirect measure of vagal efferents on the heart's sinoatrial node (Allen, Chambers, & Towers, 2007). I employed samples of undergraduates, who were most likely not experienced gamblers, and participants from the community who reported prior EGM use. Interestingly, I found that, in both samples, EGM gambling was not associated with a significant increase in heart rate, but was associated with significant decreases in RSA, suggesting decreases in parasympathetic activity. These results suggested that gambling may not induce heart rate changes as a result of excitement, but rather some other factor that instead influences the parasympathetic nervous system. One possible explanation is that increased attention toward a novel activity, such as gambling, could suppress cardiac parasympathetic activity and incidentally elevate heart rate (Duschek, Muckenthaler, Werner, & Reyes del Paso, 2009).

Though my earlier study suggested that the parasympathetic nervous system is involved in peoples' physiological responses to EGM use, I did not find an effect of immersion on RSA. This was surprising considering the fact that the parasympathetic nervous system is primarily responsible for maintaining homeostatic balance, and a number of authors have argued that flow and EGM immersion are prototypically relaxing states (Csikszentmihalyi, 2014; Schüll, 2012).

Thus, past research putatively implicates the sympathetic nervous system in gamblers' physiological responses to multiple gambling activities. However, these effects have not been entirely consistent, and have most often employed heart rate measures, confounding the sympathetic and parasympathetic branches of the autonomic nervous system. Additional measures may be useful in clearing up past controversies in the literature, and defining the phenomenon of EGM immersion and its apparent role in the development of gambling problems. In the chapters to follow, I attempt to use three distinct physiological measures to unpack the effects of EGM structural characteristics and immersion. They are 1) Respiratory Sinus

Arrhythmia (RSA, Chapter 2), as a marker of cardiac parasympathetic tone, 2) Pre-Ejection-Period (PEP, Chapter 3), as a marker of cardiac sympathetic activation (Cacioppo, Tassinary, & Berntson, 2007, *p*. 461, 619), and 3) pupillometry, as a relatively high temporal-resolution marker of autonomic nervous system responses to specific EGM events, given participants' self-reported immersion state. Neither PEP nor pupillometry have been previously examined in the context of gambling.

1.5 Summary and hypotheses

Addiction refers to a chronically-relapsing pattern of escalating, compulsive substance use or behaviour that causes significant functional impairment and continues in spite of negative life impacts. Among the burgeoning class of addictive behaviours, EGM gambling appears particularly associated with addiction harm. However, the exact nature of this relationship is blurred by complex interactions between individual traits, specific features of gambling games, and environmental factors particular to gambling venues and jurisdictions. Feelings of 'flow' or 'immersion' in EGM gambling represent one such interaction emerging from the traits of gamblers and those of gambling products. Across many studies, it is clear that this altered state of attention is an important risk factor for disordered gambling. At the same time, existing work on EGM immersion measures the state using self-report measures, an unideal practice since consensus holds that immersion alters perceptual and attentional functioning, and may therefore produce biases in survey measures. Past findings have also raised the frustrating reality that many experimental paradigms will, by attempting to measure the state, prevent immersion in gambling from occurring. Some behavioural and physiological measures may provide a less subjective, and less disruptive lens for measuring EGM immersion.

The chapters of this dissertation seek to 1) reduce subjectivity in EGM immersion research by identifying potential markers of EGM immersion beyond survey measures, and 2) better understand the behavioural and physiological correlates of EGM immersion. Whereas somatic correlates of EGM immersion may help to characterize the phenomenon, reliable markers of the experience may be readily applied to help identify immersed individuals in future research and practice. Chapters 2, 3 and 5 examine potential correlates of immersion and attention to EGM gambling in cardiac parasympathetic, cardiac sympathetic, and pupillary markers, respectively. Chapters 4 and 5 examine eye movements and behaviours towards the EGM itself, seeking behavioural correlates of EGM immersion. The experiments described in this dissertation are organized under two broad hypotheses: first, that immersion in EGM gambling produces measurable shifts in behaviour and physiological arousal, and second that EGM immersion is related to gamblers' behavioural, and physiological responses to specific EGM structural characteristics (e.g. Chapter 2), specific regions of the EGM screen (e.g. Chapter 4), and specific EGM outcomes (e.g. Chapter 5). In the concluding chapter, I remark on a number of ongoing concerns in these experiments and the broader gambling field. Drawing the collected results together, I outline the manner in which physiological and behavioural correlates of EGM immersion may reveal the potential of specific EGM devices and structural characteristics to encourage problematic gambling. My hope is that a clarified profile of EGM immersion and its effects will lead to further research, and ultimately to empirically-supported policy proposals to modify the function of modern EGMs, reducing the rate of gambling harms disproportionately associated with these devices.

Chapter 2: Effects of Bet Size and Multi-Line Play on Immersion and Respiratory Sinus Arrhythmia during Electronic Gaming Machine Use

2.1 Introduction

Public health approaches to gambling recognize a ‘player-product’ interaction in which individual factors predispose some gamblers to problematic levels of engagement, but these dispositions interact with game- and venue-level factors to produce or aggravate gambling harms (Korn & Shaffer, 1999; Murch & Clark, 2016). At the venue-level, floor layout (Finlay-Gough, 2015), ambient sound (Noseworthy & Finlay, 2009), prevailing cultural beliefs (Lim & Rogers, 2017), and proximity to other players (Rockloff & Dyer, 2007; Rockloff, Greer, & Evans, 2012; Rockloff, Greer, & Fay, 2011) have been examined in relation to gambling behaviour. In recent years, product features have received increased scrutiny, with modern Electronic Gaming Machines (EGMs, including slot machines and Video Lottery Terminals) bearing the brunt of this research interest. This is due at least in part to these games’ links to gambling-related harm (Binde et al., 2017; Breen & Zimmerman, 2002; MacLaren, 2015).

Fine-grained analyses of specific EGM features have identified a number of ingredients, including near-misses and ‘Losses-Disguised-as-Wins,’ (a product of modern, multi-line EGMs) that can distort players’ perceptions of outcomes and motivate persistent gambling (see Barton et al., 2017). Multi-line games allow players to place concurrent bets across multiple paylines on a single spin. As the many paylines occupy most of the EGM display and often overlap, playing the game on this setting is a perceptually-demanding experience. At the same time, multi-line play is associated with more frequent reinforcement and ‘smoother’ credit decrement, and experienced slot machine gamblers typically prefer gameplay on the multi-line setting (Dixon, Graydon, et al., 2014; Haw, 2008, 2009; Livingstone & Woolley, 2008; Schüll, 2012).

This study addresses game-level predictors of user experience. We aimed to test whether different bet styles on a multi-line EGM affected their immersion (termed "flow," "dissociation," and "the machine zone" by others; Dixon et al., 2017; Jacobs, 1986, 1988; Schull, 2012) in play and their attention to the game. The immersion state is prototypically described as a feeling of amplified attention to the game at the expense of all else, and has been repeatedly related to problem gambling (Cartmill et al., 2015; Diskin & Hodgins, 1999, 2001; Dixon et al., 2018; Hopley & Nicki, 2010; Kofoed, Morgan, Buchkowski, & Carr, 1997; Murch et al., 2017; Noseworthy & Finlay, 2009; Wanner et al., 2006). We believe immersion may be related to the attentional demand of play strategies that differ in complexity.

Attention was also measured using a psychophysiological proxy. Heart Rate Variability (HRV) typically decreases in response to tasks or circumstances that demand attention and/or mental effort (Lane et al., 2009; Porges & Raskin, 1969). Duschek and colleagues (2009) observed decreases in HRV related to sustained attention. In an earlier gambling study, we observed significant decreases in Respiratory Sinus Arrhythmia (RSA; an HRV metric) in response to EGM play in separate samples of university students and experienced EGM users (Murch et al., 2017). Using a driving simulator, Tozman and colleagues (2015) linked self-reported flow experiences with moderate levels of HRV when the task was challenging. As such, immersion and HRV may correlate, and both may be affected by the differing attentional demands of different EGM bet styles.

We hypothesized that immersion during EGM play would differ with multi-line versus single-line bet strategies. In a seminal study, Dixon and colleagues (2014) compared regular gamblers playing a simulated EGM on a single-line setting (1 cent on 1 pay-line = $.01 bets) and a multi-line setting (1 cent on each of 20 pay-lines = $.20 bets). Dixon et al., reported greater immersion in the multi-line condition, but the number of pay-lines was confounded by the overall bet size in that experiment. To resolve this, our study added two further conditions: one where the minimum bet is placed on multiple pay-lines, and one where the same overall bet size is achieved by increasing the number of credits bet on a single pay-line, using the bet multiplier options. This approach was also adopted by Dixon et al., (2017), who compared immersion ratings in a game played on either 20 lines at 1 credit ($.01) per line or 1 line at 4 credits ($.05) per line; a $.20 bet in both cases. There, immersion in the multi-line setting more-strongly predicted problem gambling risk. If earlier conclusions are correct, we expect that the multi-line condition will again produce higher immersion. We further hypothesized that changes in RSA across bet conditions would mirror changes in immersion across conditions. In other words, RSA should generally decrease from baseline to task, but should decrease more in blocks where multi-line strategies are employed, where we also expect immersion to be higher.

Finally, we hypothesized that salient game events (wins, 'bonus rounds'), and self-reported ADHD symptoms (Breyer et al., 2009; Waluk et al., 2016) may also influence immersion and cardiac activity during EGM play.

2.2 Methods

2.2.1 Participants

This study was approved by the University of British Columbia's Behavioural Research Ethics Board. We recruited 80 male undergraduate students. This study also investigated impedance cardiography (see Chapter 3). Thus, sampling was restricted to male participants because impedance cardiography involves applying adhesive electrodes to shirtless participants. Inclusion criteria allowed participants: ages 19 years or older (the legal age to gamble in this jurisdiction), with normal or corrected-to-normal eyesight, with no history of allergic reaction to adhesives or gels, and no current or recent use of psychotropic or cardiac medications. Individuals who reported high risk of problem gambling on the PGSI (see below) were not permitted in the slot machine task.

Participants responded to an online advertisement hosted by the school's psychology department, and received partial grade credit. Four participants did not complete the study after providing consent; one reported high risk of problem gambling, one displayed a persistent cardiac arrhythmia, one withdrew citing concerns about adhesive electrode placement on body hair, and one session was halted due to a power outage. Thus, the final sample size was 76 (mean age = 20.55, SD = 2.37).

2.2.2 Procedure

After providing consent, participants completed the Problem Gambling Severity Index (PGSI; Ferris, Wynne, Ladouceur, Stinchfield, & Turner, 2001). Items were scored from 0 to 3 ("never," "sometimes," "most of the time," or "almost always"), for a total of 27 possible points (0 = non-problem gambler, 1-2 = low-risk, 3-7 = moderate risk, 7 or greater = high risk / problem gambler).

Participants completed the Adult ADHD Self-Report Scale (ASRS; Kessler et al., 2005). Responses are given on a 5-point Likert scale ("never," "rarely," "sometimes," "often," or "very often,"). For the purpose of these analyses, we chose to treat the scores on the six items as continuous (see Seli, Smallwood, Cheyne, & Smilek, 2015).

Electrodes were connected and a 5-minute, eyes-closed baseline recording was obtained. The game, "Buffalo Spirit," is a genuine WMS slot machine (Scientific Games Co., Las Vegas, NV) configured on a 1 cent minimum bet with 40 paylines. The bet multiplier buttons allow the player to place 1 to 5 times the minimum bet at each line. The game had a configured hold percentage of 11% (i.e., over thousands of spins the machine would on average keep 11 cents for every dollar wagered). Participants were informed that the game was real, and had not been modified. They were briefed on EGM gameplay. Participants were informed that they would be playing "a number of different betting strategies for a few minutes each." They were told they would be endowed CAD $40 cash to load into the machine for each block, and that, "depending on how much credit [they had] at the end, [they would] be paid a bonus of up to $12." The exact nature of these bonus payments (described below) was laid out on the consent form.

The slot machine session was divided into four 5-minute blocks. Each block required players to use a pre-determined betting strategy (order was counterbalanced using a Latin square design). The 'Small Bet' strategy comprised the minimum bet on a single payline (1 line, 1 credit per line, $0.01/bet), 'Large Bet' comprised many lines with multiple credits bet on each (20 lines, 5 credits per line, $1.00/bet; made 100x larger than the Small Bet condition in order to emphasize the difference), and two intermediate strategies achieved a $0.05 bet by increasing either the number of paylines ('Line-Style', 5 lines at 1 credit, $.05/bet) or the bet multiplier ('Multiplier-Style', 1 line at 5 credits, $.05/bet). With these constrained bets, we compared a minimum bet to a much larger bet, as well as two equally-sized intermediate bets which contrast the games' multi-line and bet-multiplier features. Notably, the Line-Style condition produced wins on 5 different paylines dispersed around the screen, while the Multiplier-Style condition produced wins only on the middle payline. Since multi-line play increases the frequency of wins, and since winning paylines are typically outlined on-screen when triggered by multi-line games, we reasoned that players might expend more attention on the Line-Style condition than the Multiplier-Style condition. Additionally, players may be more vigilant towards multi-line EGMs if they engage in visual searches for matching symbols before the last reel comes to a stop. Such behaviour would also draw upon attentional resources.

For the two multi-line conditions (Large Bet and Line-Style), participants could be exposed to LDWs, and saw a greater likelihood of triggering the 'replicating' bonus feature, which duplicates winning symbols randomly across the reels. All conditions were equally likely to trigger the 'free-spins' bonus feature, as it does not rely on a payline win. Compared to simple wins, bonus features are rare and highly salient, and may be a driving motivator for problem slot machine use (Livingstone & Woolley, 2008; Lole & Gonsalvez, 2017).

Following each block, participants completed a 7-item immersion questionnaire. The scale is a concatenation of two previously-employed measures: the 'Flow' subscale of the Game Experience Questionnaire (IJsselsteijn et al., 2013) (e.g. "I felt completely absorbed") and the Diskin and Hodgins (1999) modification of the Dissociation Questionnaire (Jacobs, 1986, 1988) ("I felt like I was in a trance", "I lost track of time"). Each response was obtained on a 5-point Likert scale ("very slightly or not at all," "a little," "moderately," "quite a bit," "extremely,") and divided by 7. We previously used these measures jointly (Murch et al., 2017), finding that they tend to provide concordant results. Reliability analyses in the present study indicated that these questionnaires were well-suited to concatenation. Cronbach's α for the average rating (across four blocks) participants gave each of the seven items in the immersion questionnaire was .88. Cronbach's α was .82 for the Dissociation Questionnaire and .80 for the Game Experience Questionnaire items.

After the fourth and final block, participants were debriefed on the study, the mathematic and statistical rules governing gambling, and hold percentage. They were provided documents describing the functioning of modern, multi-line slot machines and a list of available gambling treatment services in this jurisdiction. Credit losses and gains for each session were totaled; 22 individuals turned a profit overall, each being paid $12. For participants at a net loss, payments decreased by $2 for each 800 credits lost, to a minimum of $2 paid to participants who lost 4000 credits or more (n = 8). Physiological data from a block was discarded if the participant ran out of credits.

2.2.3 Heart Rate Variability

Psychophysiological data were sampled at 1,000 Hz using a wireless BIOPAC MP150 system. Participants wore seven Ag/AgCl electrode patches from Vermed (Buffalo, NY). Three electrocardiogram (ECG) electrodes were affixed to the chest and lower left abdomen. Four patches were applied to the bilateral neck and ribcage for impedance cardiogram measures. Seventeen participants' ECG data was insufficiently clean or complete for use in these analyses. Where correlational analyses were performed with individual task bins and baseline values, all available data was used.

Heart Rate (HR) and RSA were extracted from the ECG traces using QRSTool CMetX (Allen et al., 2007). RSA is a marker of cardiac vagal tone, with widespread use in the HRV field (Allen et al., 2007). QRSTool was used for inspection and cleaning of ECG traces. Heart beats' r-wave peaks were automatically marked above visual-inspection threshold, producing a time-series distribution of peak-to-peak latencies (ms). Single missing peaks were linearly interpolated. Consecutive missing peaks triggered the exclusion of that block. Upon export, the generated time-series data were calculated as HR and RSA using CMetX. RSA is defined there as the natural log of the 0.12-0.40 Hz band-limited variance of the time series.

We used a Biopac Respiration Effort Transducer to observe respiration rate for each block (see Grossman & Taylor, 2007). These data were resampled to 62.5 Hz and a 0.05 – 1 Hz band pass was applied. Heart rate is reported alongside RSA as recommended (Grossman & Taylor, 2007).

One-way within-subjects ANOVAs were conducted, and corrected using Greenhouse-Geisser fractional degrees of freedom where the assumption of sphericity was violated under Mauchly's test. Pairwise comparisons were Bonferroni corrected.

2.3 Results

2.3.1 Self-report and Gameplay Data

Participants' PGSI scores were generally low (Mean = 1.22, SD = 1.73); 39 individuals were in the non-problem gambler category (PGSI = 0), 22 individuals were low risk and 15 were moderate risk. The mean ASRS score was 10.64 (SD = 3.15).

Wins and bonus features, as well as the overall number of credits lost, varied by block. For the Small Bet blocks, the median participant encountered 1 win (SD = 0.90), 1 bonus feature (SD = 0.89) and lost 6.88 credits (of 4000, SD = 67.01). For the Large Bet blocks, the median participant encountered 6 wins (SD = 2.56) and 2 bonus features (SD = 1.09), and lost 867.63 credits (SD = 3096.29). The median Line-Style block had 3 wins (SD = 1.81), 1 bonus feature (SD = 0.84), and incurred a loss of 57.71 credits (SD = 296.22). The median Multiplier-Style blocks had 1 win (SD = 1.05), 0 bonus features (SD = 0.68), and 49.21 credits lost (SD = 240.49).

Immersion scores differed significantly between blocks ($F(2.62, 196.21) = 14.24$, $p < .001$, $\eta^2 = 0.16$, $\varepsilon = .87$, figure 1). The Large Bet condition was more immersive than the Small Bet condition ($p < .001$), and both intermediate conditions (Line-Style $p = .02$, Multiplier-Style $p < .001$). The Line-Style condition was more immersive than the Small Bet condition ($p = .01$) and did not differ from the Multiplier-Style ($p = .69$). The Multiplier-Style condition did not differ from the Small Bet condition ($p = .18$). To test whether immersion was associated with reinforcement, we ran exploratory correlations of immersion scores with the number of wins and bonus features in each block. The number of bonus features in the Large Bet condition was significantly related to immersion (r(74) = .28, p = .02; all other bonuses p > .10), and we note this would not survive correction for multiple comparisons. The number of wins experienced was not a significant predictor of immersion under any bet style (all p > .20).

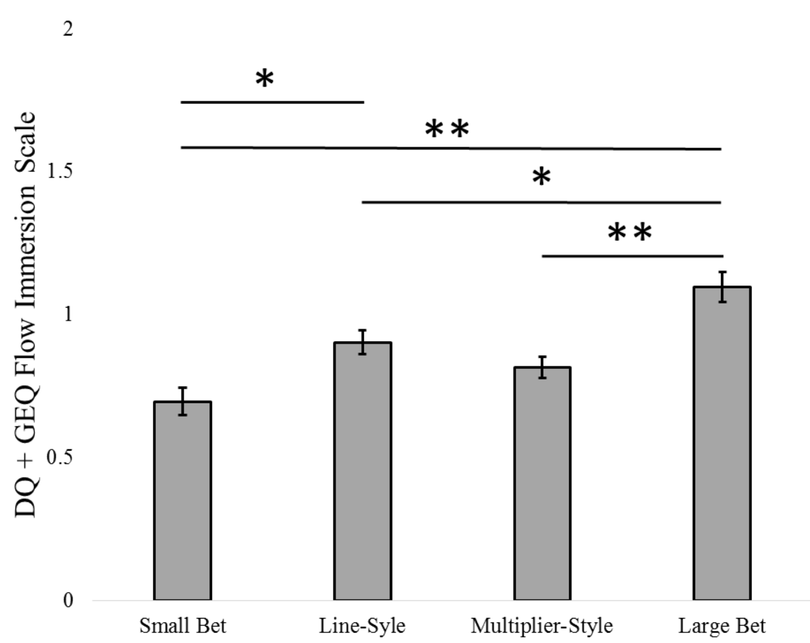

Figure 1. Immersion ratings (out of 4) by bet condition.

Note: Bars represent one standard error within-subjects (Cousineau, 2005; Morey, 2008). Lines indicate statistical significance of the pairwise comparisons. * $p < .05$, ** $p < .01$

Problem gambling risk category (PGSI) was tested as a between-subjects factor on the immersion model. Neither a significant main effect ($F(2, 73) = 2.68$, $p = .08$, $\eta^2 = .07$), nor an interaction were observed ($F(5.27, 192.36) = 0.71$, $p = .62$, $\eta^2 = .02$, $\varepsilon = .88$), though the repeated-measures effect remained ($F(2.64, 192.36) = 14.12$, $p < .001$, $\eta^2 = .16$, $\varepsilon = .88$). We note, however, that the restricted range of PGSI scores in our sample could have impacted these results. ASRS was median-split and tested as a between-subjects factor on the immersion model. A significant main effect ($F(1, 74) = 4.23$, $p = .04$, $\eta^2 = .05$) indicated greater immersion among high-ASRS participants, but there was no interaction by block ($F(2.63, 194.23) = 0.52$, $p = .65$, $\eta^2 < .01$, $\varepsilon = .88$).

2.3.2 Psychophysiological Results

A repeated-measures ANOVA was performed on the RSA data. A significant main effect of baseline/condition was observed ($F(1.64, 94.89) = 18.25$, $p < .001$, $\eta^2 = .24$, $\varepsilon = .41$, figure 2). Pairwise tests indicated that RSA was significantly lower during all EGM conditions relative to the pre-task baseline (all $p < .001$). None of the task conditions differed significantly from one another (all other $p > .99$). Median-split ASRS had a significant between-subjects effect on the RSA model such that high-ASRS participants had lower overall RSA ($F(1, 57) = 6.01$, $p = .02$, $\eta^2 = .10$), consistent with relative deficits in emotion regulation (Holzman & Bridgett, 2017). The interaction term was not significant ($F(1.63, 92.61) = 0.23$, $p = .75$, $\eta^2 = .004$, $\varepsilon = .41$).

Baseline RSA was subtracted from RSA for each slot machine condition and the change scores were correlated with their associated immersion ratings. RSA change from baseline significantly predicted immersion scores during the Multiplier-Style session type ($r(67) = -.34$, $p = .02$). In this condition, immersion increased as RSA decreased from baseline. All other comparisons were not statistically significant ($p > .99$).

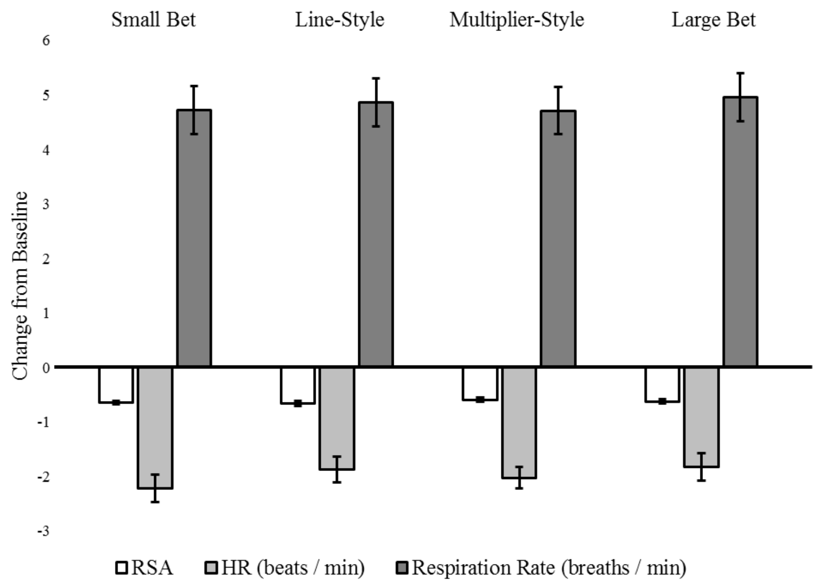

Figure 2. RSA, HR and respiration rate change from baseline by bet condition.

Note: Bars represent one standard error for the within-subjects effects.

The time-course of RSA was analyzed to determine if RSA changed as the session progressed. Blocks were labelled chronologically, ignoring play condition. Pairwise tests indicated no significant differences between task blocks (all task-related comparisons $p > .50$, figure 3).

Secondary models tested for changes in respiration rate and heart rate. A task-related increase in respiration was observed ($F(1.99, 115.62) = 82.11$, $p < .001$, $\eta^2 = .59$, $\varepsilon = .50$, figure 2), with differences between baseline recording and task blocks (all $p < .001$), but not between task blocks (all $p > .99$). Respiration rate predicted RSA (all $p < .04$). Heart rate also varied by block ($F(2.46, 142.77) = 7.34$, $p < .001$, $\eta^2 = .11$, $\varepsilon = .62$, figure 2), decreasing from the baseline recording to all EGM conditions (all $p < .03$), but no EGM blocks differed (all $p > .99$).

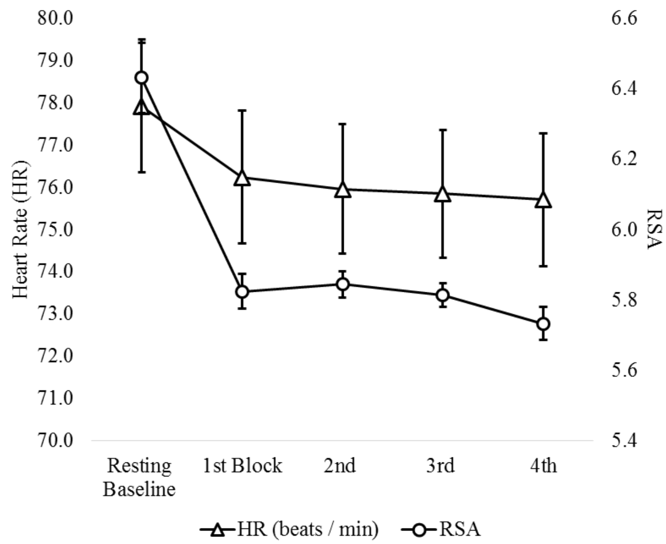

Figure 3. Time-course graphs of HR and RSA.

Note: Bars represent one standard error for the within-subjects effects.

2.4 Discussion

This study examined differences in RSA and self-reported immersion, which were conceptualized as markers of attention, as a function of different EGM bet style. Our student participants, who were mostly novice gamblers, reported substantially higher immersion scores in the Large Bet condition compared to the Small Bet condition. These results corroborate Dixon and colleagues' (2014) findings, showing that player immersion is maximized when the number of paylines and the overall bet amount are both high. Immersion was also higher in the Large Bet condition compared to the two intermediate conditions, indicating an additive effect of paylines and bet size. In comparing these intermediate conditions against the Small Bet condition, only the Line-Style condition showed a significant increase in immersion; changing the bet by itself in the Multiplier-Style condition did not facilitate immersion.

Some of the relationship between immersion and bet style could be explained by the number of EGM bonus features, which varied in our study due to the use of authentic EGMs. In the Large Bet condition - which produced the highest overall number of bonus features on average - a significant relationship was seen between the number of bonus features and immersion scores. While our participants were generally not experienced EGM users, prior research found that regular players favour games with free spin bonus features (Livingstone & Woolley, 2008). Acknowledging that much EGM work relies on simulators without bonuses, these features certainly merit further research.

We observed significant relationships with self-reported ADHD symptoms between both immersion and RSA. Participants with higher ASRS scores reported greater immersion in gambling, and had lower RSA across all bet styles. This effect on RSA indicates poorer top-down self-regulation among individuals with ADHD traits (Holzman & Bridgett, 2017), consistent with prior research where lower RSA was associated with emotion regulation deficits in children treated for ADHD (Beauchaine et al., 2013). Since no consistent relationship between immersion and RSA was observed, these relationships are not likely to confound our interpretation of the immersion data.

We further hypothesized that different bet styles would produce in-kind reductions in RSA, since multi-line and large bet strategies should impose greater attentional demands. This hypothesis was not supported. Rather, we saw significant and uniform decreases in RSA compared to baseline levels. There are a number of possible explanations for this null result.

Perhaps EGMs at any setting are sufficiently demanding of attention to trigger parasympathetic withdrawal even in the Small Bet condition, creating a floor effect. This interpretation would help to explain why some participants show marked decreases in the ability to perform simple peripheral target-detection tasks while playing EGMs (Diskin & Hodgins, 1999, 2001; Murch et al., 2017). Alternatively, outlining winning paylines with salient colours could nullify, or at least attenuate, the increased attentional demands of multi-line play by allowing wins to be pre-attentively processed regardless of the number of paylines played.

Another likely factor is the relationship with respiration rate, which showed a similar response pattern to RSA. Indeed, one frequency-domain examination of RSA suggests that its covariation with attention is due to changes in respiration (Althaus, Mulder, Mulder, Van Roon, & Minderaa, 1998). If so, why does EGM use increase respiration? Perhaps our resting baseline led to a conscious control of breathing rate by some participants. Future studies could establish multiple baselines (e.g. one during a paced breathing instruction) to capture this effect. Certainly, future research on cardiac function during gambling, and particularly HRV measurement, would benefit from direct recording of respiration.

Several limitations should be acknowledged. Our student sample registered low levels of gambling involvement and PGSI scores, and thus our results do not speak to disordered gambling. Indeed, the makeup of our sample (younger adults, all male) does not match the demographic makeup of EGM patrons in most jurisdictions. The use of a hybrid casino laboratory allows us to study genuine EGMs in a highly-controlled environment, however some concern exists with respect to ecological validity (Anderson & Brown, 1984; S. H. Stewart et al., 2002). It is notable, for example, that heart rate decreased during EGM play in our experiment; a number of studies have reported HR increases during EGM use in naturalistic environments

(Coventry & Constable, 1999; Coventry & Hudson, 2001; Diskin & Hodgins, 2003; Griffiths, 1993). One possible explanation for the observed decrease is that participants had slightly elevated heart rates in the unusual laboratory setting that were most pronounced during the initial baseline, and abated over time as they became familiar with their surroundings. We aimed to examine attentional differences using heart rate variability, though its close ties to respiration suggest it may not be the best tool for research on EGM users. We note also that the cleaning of the cardiac data resulted in a smaller subsample of participants compared to the immersion analyses, reducing statistical power. A clear avenue for future research lies in applying eye tracking to monitor attentional allocation during EGM play, and relationships with immersion.

Chapter 3: Investigating Flow State and Cardiac Pre-Ejection Period during Electronic Gaming Machine Use

3.1 Introduction

> "Although it is possible to flow while engaged in any activity, some situations appear to be designed almost exclusively so as to provide the experience of flow."
>
> -Mihaly Csikszentmihalyi

Flow – the trance-like experience of extreme focus on a task or activity – is often described in the context of leisure activities such as rock climbing, chess, or art (Csikszentmihalyi, 2014; Jackson & Marsh, 1996; Stavrou, Psychountaki, Georgiadis, Karteroliotis, & Zervas, 2015). The experience is typically associated with increases in positive affect (Asakawa, 2004; Csikszentmihalyi, 2014; Murch et al., 2017; Rogatko, 2009). According to Flow Theory, some activities are particularly adept at eliciting and sustaining the flow experience, and gambling has been proposed as one such 'flow activity' (Csikszentmihalyi 2014, p. 140, 146). A negative implication is that businesses may offer products specifically designed to encourage flow, capitalizing on prolonged or more frequent participation by individuals who are seeking to escape from stress or low mood (Dixon et al., 2018; Schüll, 2012).

Researchers first became interested in the flow-related aspects of gambling in the 1980s. Jacobs (1986) proposed that gambling activities can provide a pleasurable, trance-like sensation that reduces gamblers' self-awareness. He suggested that this state of absorption in gambling was akin to the clinical symptom of dissociation, although in modern accounts it appears more characteristic of non-pathological or ‘normative’ dissociation (Butler, 2006; Thomson & Jaque, 2012). Jacobs posited that this state of absorption could contribute to gambling addictions, and that these experiences could be addictive in-and-of-themselves (Jacobs, 1986, 1988). One study aimed to directly compare Csikszentmihalyi’s and Jacobs’ constructs in samples of student athletes and problem gamblers (Wanner et al., 2006). Results showed that the problem gambler group endorsed every item on both the Flow Trait Scale, and Jacobs’ “Dissociation Questionnaire” (Jackson & Marsh, 1996; Jacobs, 1986). In an earlier analysis of data in the current study, we reported high internal consistency between items on the Dissociation Questionnaire (which includes feelings of being “in a trance,” and losing track of time; Jacobs,1986), and the Flow subscale of the Game Experience Questionnaire (“I felt completely absorbed,” “I forgot everything around me”; IJsselsteijn, de Kort, & Poels, 2013; Murch & Clark, 2019; Poels & Kort, 2007), again suggesting considerable overlap between Flow Theory and Jacobs’ absorption construct (but see Murch et al., 2019).

The susceptibility of regular gamblers to experiencing gambling flow is reliably associated with symptoms of disordered gambling; the Dissociation Questionnaire has been repeatedly correlated with measures of problem gambling (Cartmill et al., 2015; Diskin & Hodgins, 1999; Dixon et al., 2018; Hopley & Nicki, 2010; Kofoed et al., 1997; Murch et al., 2017; Murch, Limbrick-Oldfield, et al., 2020; Noseworthy & Finlay, 2009; Wanner et al., 2006). In two experiments, gamblers were asked to monitor an area off-screen at the same time as they gambled on an Electronic Gaming Machine (EGM; including modern slot machines), providing a response when target shapes appeared off-screen (Diskin & Hodgins, 1999; Murch et al., 2017). In both studies, levels of problematic gambling were associated with reduced detection of peripheral targets while gambling. This effect is consistent with the ‘attentional narrowing’ mechanism proposed in Flow Theory (Csikszentmihalyi, 2014, p. 139). A more granular investigation of gambling flow found that specific flow experiences may have protective (losing track of time, autotelic experiences) or aggravating (senses of concentration and control) effects on gambling harms (Trivedi & Teichert, 2017; see also Palomäki & Laakasuo, 2016).

Some forms of gambling may be especially good at eliciting flow. EGMs are disproportionately associated with problem gambling (Binde et al., 2017; Breen & Zimmerman, 2002; Gainsbury, Angus, & Blaszczynski, 2019; MacLaren, 2015). Recent accounts of EGM gambling have argued that these devices may be designed to maximize 'time on device', conceivably via flow experiences (Schull, 2012, p. 74). In an Australian survey of gamblers who endorsed feeling "in a trance" while gambling, 79% of respondents had been using an EGM at the time (Office for Problem Gambling, 2006). Several scholars have proposed that absorption in EGM gambling may be an effective (though ultimately maladaptive) coping strategy for those seeking to avoid symptoms of depression, anxiety, or stress (Dixon, Gutierrez, Stange, et al., 2019; Dixon et al., 2018; Schüll, 2012).

Current research relies heavily on self-report measures of flow, which can be susceptible to disruption (e.g. by introducing a secondary task; Murch et al., 2017). Psychophysiological methods may provide alternative markers for investigating the gambling flow phenomenon more covertly. Past examinations of EGM use have suggested a role for both the sympathetic (Anderson & Brown, 1984; Coventry & Constable, 1999; Coventry & Hudson, 2001; Griffiths, 1993) and parasympathetic nervous systems (Murch et al., 2017; Murch & Clark, 2019b). However, little evidence exists for a link between gambling flow and physiological measures. In two experiments, we found no significant relationships between EGM flow and respiratory sinus arrhythmia, a cardiac marker of parasympathetic nervous system tone (Murch et al., 2017; Murch & Clark, 2019b).

The present study evaluated the relationship between gambling flow and sympathetic nervous system arousal, indexed by cardiac pre-ejection period (PEP). PEP is an impedance cardiography-derived metric, which approximates the interval between onset of the electrical signal that stimulates left ventricular contraction (QRS complex) and opening of the aortic valve (commencement of blood efflux from the left ventricle into the aorta). In human studies and animal models, PEP has demonstrated excellent validity as an inverse measure of sympathetic arousal (Cacioppo, Tassinary, & Berntson, 2007, *p*. 461, 619). PEP is understood to reflect sympathetic nervous system arousal because stimulation of cardiac β-adrenoreceptors increases ventricular contractility, raising intra-ventricular pressure, and shortening the latency between the onset of left ventricular contraction and the point when ventricular pressure exceeds aortic pressure and the aortic valve opens (Lozano et al., 2007). In human studies, PEP has been observed to decrease (indicating sympathetic arousal) in response to anger, disgust, and fear emotional induction, and increase in response to happiness, sadness, and amusement (Kreibig, 2010). PEP is also sensitive to reward anticipation and delivery: PEP decreased when participants anticipated social reward (Brinkmann & Franzen, 2017), and was linearly related to reward size in delayed-match-to-sample tasks (Brinkmann & Franzen, 2013; Richter & Gendolla, 2009).

We report data from three laboratory experiments, in which self-reported flow and PEP data were collected for an EGM gambling session that lasted at least 15 minutes. We first hypothesized that PEP would decrease (relative to baseline) in response to EGM gambling, indicating sympathetic nervous system arousal associated with the gambling activity. We divided the gambling sessions into 5-minute blocks to test the time-course of this response, as the effects of gambling on PEP may not be uniform across a gambling session. Our second and primary hypothesis proposed that EGM-related changes in PEP would interact significantly with participants' flow ratings.

3.2 Methods

3.2.1 Participants

The studies included in these analyses were approved by UBC's Behavioural Research Ethics Board. Participants were recruited to three separate experiments conducted between 2015 and 2018 (N_1 = 121, age M = 21.25, SD = 2.91; N_2 = 80, age M = 20.55, SD = 2.37; N_3 = 106, age M = 20.80, SD = 2.39, Figure 4). Primary analyses for Studies 1 and 2 are already published (Ferrari, Chan, Brown, & Clark, 2018; Murch & Clark, 2019b), without the measures of PEP. Study 3 has not been submitted for peer-reviewed publication (Murch, 2016). Study 1 was primarily interested in examining testosterone change in relation to EGM gambling. Study 2 looked at levels of flow and heart rate variability during EGM gambling with differing bet strategies tested within-subjects. Study 3 examined gambling immersion using a social manipulation, in which participants who provided psychophysiological data were, in some cases, tested alongside other participants seated at adjacent EGMs. Participants in Studies 2 and 3 gambled while an experimenter seated behind them monitored the physiological recording. Participants in Study 1 gambled without anyone else in the room. All participants were male undergraduate students, at least 19 years of age, who responded to an online advertisement posted by the psychology department. Most participants were compensated with partial course credit, though some participants in Study 1 were paid $15 CAD instead. Participants were included only if they were not high-risk problem gamblers (i.e. problem gambling severity index score < 8, see below), had no allergies to gels or adhesives, and no current prescriptions for psychotropic or cardiac medications.

3.2.2 Questionnaires

Participants completed the Problem Gambling Severity Index (PGSI), which probes past-year problem gambling symptoms (Ferris & Wynne, 2001). Responses to the nine items were rated on a 4-point Likert scale ranging from "Never" (0), to "Almost always" (3), and a total score was obtained.

After gambling on the EGMs, participants completed the Flow subscale of the Game Experience Questionnaire (GEQ; "I felt completely absorbed," "I forgot everything around me"; IJsselsteijn et al., 2013; Poels & Kort, 2007). In Study 2, participants completed this questionnaire after each of four 5-minute gambling blocks. Responses were given on a 5-point Likert scale ranging from "Not at all" (0), to "Extremely" (4). Scores for the two items were averaged, and scores were standardized within each study. Past analysis of these items in Study 2 indicated relatively high reliability estimates (Cronbach's $\alpha = 0.80$; Murch & Clark, 2019).

3.2.3 Procedure

After providing written consent, participants completed the PGSI. Individuals scoring greater than 7 (indicating high risk problem gambling), on this measure were excluded from the gambling task, and instead proceeded straight to debriefing. The lab was then cleared of any additional participants, and participants providing physiological data were asked to remove their shirt for electrode placement. For the impedance signal, we applied eight Ag/AgCl electrodes

(Vermed, Buffalo, NY); four were applied laterally on the neck, and four were applied laterally on the chest below the armpit (e.g. Gramzow, Willard, & Mendes, 2008). For an electrocardiogram, we then applied 3 electrodes to the upper left pectoral, upper right pectoral and lower left abdomen. The data were relayed wirelessly to the RSPEC-R and NICO-R modules of a Biopac MP150 system (Goleta, CA) recording at 1,000 Hz. Participants then put their shirts on and provided a five-minute baseline recording in a seated position. In Study 1, participants' baseline recording was obtained at the same time as they provided a saliva sample via passive drool into a small vial. Participants in Studies 2 and 3 were instructed to close their eyes during the baseline recording, but did not provide a saliva sample.

In each study, participants gambled on a genuine EGM for at least 15 minutes. Each EGM was a modern, multi-line device (see Dixon et al., 2014), set on a 1 cent denomination (i.e. if betting on a single line, each spin would cost $0.01). In Study 1, participants gambled continuously on the EGM "Dragon's Fire" (Scientific Games Co., Las Vegas, NV). Study 2 consisted of four 5-minute gambling blocks on the EGM "Buffalo Spirit," (Scientific Games Co., Las Vegas, NV). Study 2 participants completed the GEQ Flow questionnaire after each block. This introduced a break lasting approximately 1-minute between blocks. Participants who provided PEP data in Study 3 gambled on "Double Diamond," or "Triple Diamond," (IGT, Las Vegas, NV). Participants in all studies were provided $40-60 CAD (equivalent to 4,000-6,000 in-game credits) to use on the machine. Each study constrained participants' betting strategies in some way. In Studies 1 and 3, a multi-line bet strategy was set, at $0.40 and $0.20 respectively, to ensure frequent reinforcement (Livingstone & Woolley, 2008; Murch et al., 2017). In Study 2, bet strategies were systematically manipulated, from 1 credit bet on 1 payline (i.e. a $0.01 bet, the minimum), to 5 credits bet on each of 20 paylines (i.e. $1.00 per spin). Each study involved a cash bonus incentive: participants in Study 1 were paid a $10 bonus if they finished the session in profit (i.e. over 4,000 credits), whereas participants in Studies 2 and 3 received a variable bonus from $2 to $12 based on their remaining credits.

3.2.4 Processing and Analyses

PEP is defined as the latency between Q-wave onset in an electrocardiogram, which reflects the onset of the electrical signal prompting left ventricular contraction, and the upward inflection point (B) in the derived impedance signal, dZ/dt (Cacioppo et al., 2007). In order to address our time-course hypotheses and retain comparability to baseline recordings, PEP data were partitioned into 5-minute blocks. As 15 minutes was the shortest session length, we extracted the first three blocks (0-5, 5-10, and 10-15 minutes) from each study. Physiological data were visually inspected for artifacts. Blocks were excluded in cases where either the participant had run out of credit and stopped gambling, or serious artifacts precluded an accurate extraction of PEP. PEP extraction was completed using the pre-ejection period algorithm in Acqknowledge 4.4 (Biopac, Goleta, CA). Complete or partial PEP data was available for 218 participants across the three studies (Figure 4). Baseline PEP scores were subtracted from PEP scores for each block. This array of difference scores represents the change in PEP from baseline to each block, the dependent variable “ΔPEP”.

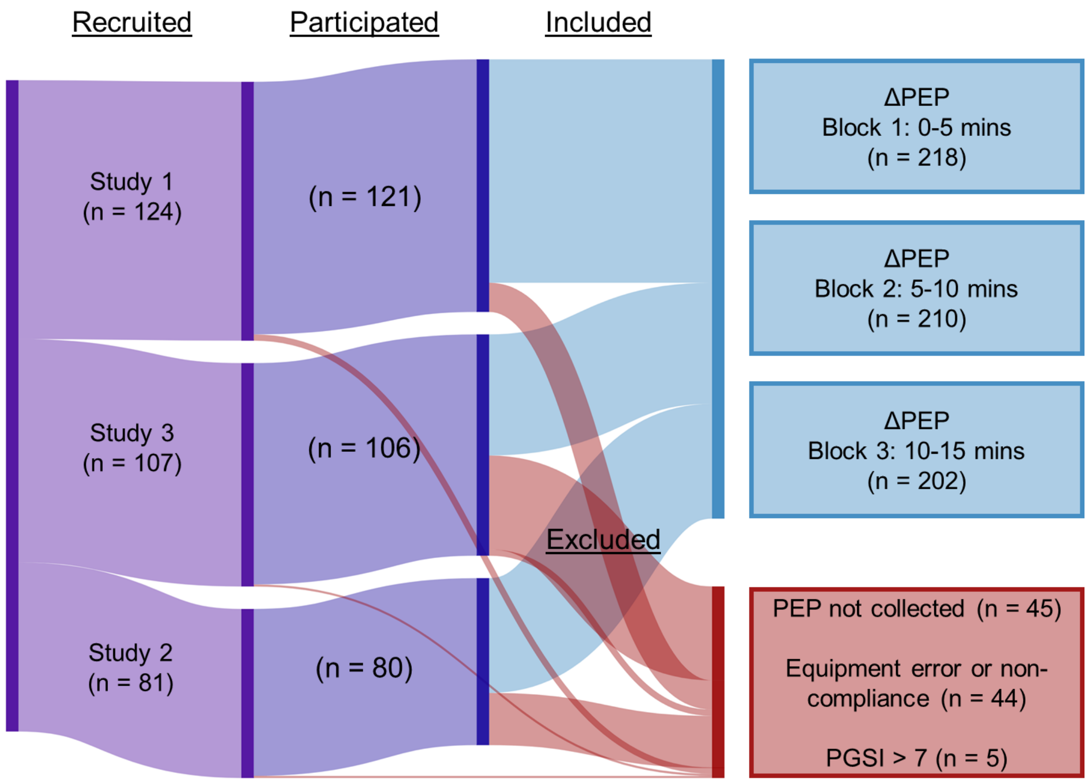

Figure 4. Inclusion flowchart.

We performed three linear multilevel regression models with maximum likelihood estimation to predict ΔPEP given the block in which it was recorded, and the self-reported flow state score associated with that block. Participants in study 2 gave flow ratings for each of the three blocks separately, while participants in Studies 1 and 3 gave a single flow rating for all blocks after the session was completed. ΔPEP blocks were nested within participants and studies, and we examined indices of model fit (AIC and BIC) to determine that these factors should be modeled as random effects (A. Field, 2012). Block and study number were dummy-coded. Since ΔPEP was calculated by subtracting baseline PEP levels, a value that reflects no task-related change is necessarily equal to zero, and as such the model intercept was suppressed. Models 1 and 2 directly address our hypotheses. Model 3 was included in order to explore the simple main effects of block and study on the relationship between flow and PEP. This allowed us to investigate whether any effects observed in model 2 appeared heterogeneously across different experimental contexts.

Model 1: ΔPEP predicted by block number.

Model 2: ΔPEP predicted by block number, and block-by-flow interaction terms

Model 3: ΔPEP predicted by block number, and block-by-flow-by-study interaction terms

Analyses were performed in JASP, and R version 3.5.2, using the “nlme” package (Fox & Weisberg, 2011; JASP Team, 2019; Pinheiro, Bates, DebRoy, Sarkar, & R Core Team, 2019; R Core Team, 2018). To assess the underlying assumptions of linearity and homoscedasticity, we calculated variance inflation factors and visually inspected the distributions of fitted and residual values at the levels of the factors and random effects. We were satisfied that the models did not violate the underlying assumptions of the analyses. These data and analyses have been publicly archived[1].

3.3 Results

The overall mean PEP during baseline blocks was 106.00 ms (SD = 21.79 ms). Task-related PEP levels were comparable during Block 1 (mean = 105.98 ms, SD = 22.17 ms), Block 2 (mean = 105.32 ms, SD = 19.87 ms), and Block 3 (mean = 106.47 ms, SD = 20.36 ms). The mean GEQ Flow score was 1.62 (SD = 1.12) in Study 1, 1.14 (SD = 0.72) in Study 2, and 1.21

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[1] https://dataverse.scholarsportal.info/dataset.xhtml?persistentId=doi:10.5683/SP2/JFR1B3

(SD = 1.02) in Study 3, indicating mild-to-moderate levels of flow in the three experiments. A one-way ANOVA indicated that the average GEQ Flow scores differed significantly between the three studies ($F(2, 197.62) = 6.93$, $p = .001$; Welch correction employed due to unequal variances), with higher scores in Study 1 than Study 2 ($p_{\text{Bonferroni}} = .004$), and Study 3 ($p_{\text{Bonferroni}} = .007$), but not between Studies 2 and 3 ($p_{\text{Bonferroni}} > .99$).

3.3.1 Regression Model Results

Model 1: Overall, there was no significant change in PEP relative to baseline levels (Block 1: $B = 0.51$, $t(408) = 0.51$, $p = .61$; Block 2: $B = -0.37$, $t(408) = -0.36$, $p = .72$; Block 3: $B = 0.61$, $t(408) = 0.60$, $p = .55$).

Model 2: ΔPEP again did not differ significantly from baseline for Block 1 ($B = 0.70$, $t(405) = 0.70$, $p = .48$), Block 2 ($B = -0.22$, $t(405) = -0.22$, $p = .83$), or Block 3 ($B = 0.72$, $t(405) = 0.71$, $p = .48$). The block-by-flow interaction term was significant for Block 1 ($B = -1.89$, $t(405) = -2.13$, $p = .03$), but not for Block 2 ($B = -0.87$, $t(405) = -0.96$, $p = .34$), or Block 3 ($B = -0.50$, $t(405) = -0.56$, $p = .58$). The model fit was not significantly improved over Model 1 ($X^2(3) = 5.24$, $p = .16$).

Model 3: ΔPEP did not differ significantly from zero for Block 1 ($p = .89$, Table 1), Block 2 ($p = .56$), or Block 3 ($p = .69$). In Study 1, ΔPEP interacted significantly with flow during Block 1 ($p = .01$, Figure 5), but not during Block 2 ($p = .11$) or Block 3 ($p = .33$). In Study 2, ΔPEP interacted significantly with flow during Block 1 ($p = .02$), but not during Block 2 ($p = .40$), or Block 3 ($p = .25$). Lastly, in Study 3, ΔPEP interacted significantly with flow during Block 1 ($p = .02$), but not during Block 2 ($p = .10$), or Block 3 ($p = .10$). Notably, the direction of the Block 1 effect differed from those observed in Studies 1 and 2. The model fit was significantly improved over Model 2 ($X^2(6) = 16.03$, $p = .01$).

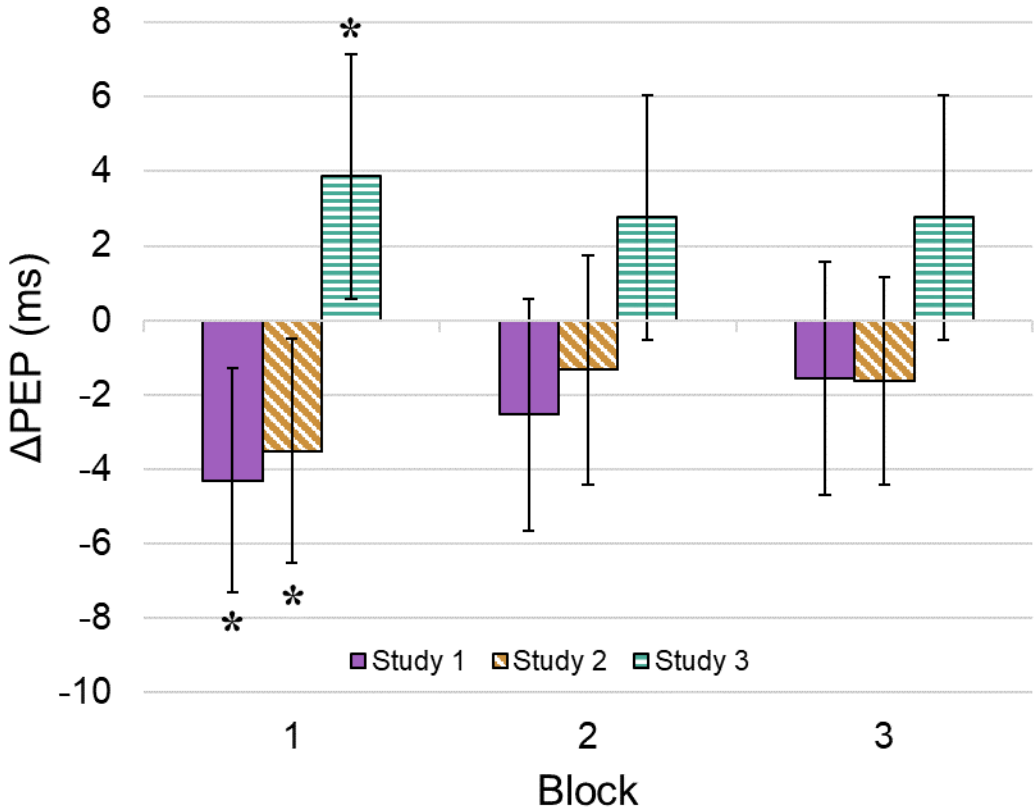


Figure 5. Block-by-flow-by-study interactions

Note: Plotted values represent interaction effect coefficients summarized in Table 1 (i.e. data points represent predicted change in PEP from baseline for a participant whose immersion score was 1 standard deviation (SD) above the mean). For example, the mean flow rating in Study 3 was 1.21 (SD = 1.02). A participant who gave a flow rating of 2.23 (+1 SD) in Study 3 is expected to have a 3.87 ms increase in PEP during block 1 compared to their baseline level. A participant who gave a flow rating of 0.19 (-1 SD) in Study 3 is expected to have a 3.87 ms decrease in PEP during block 1. Bars represent the 95% confidence interval. * $p < .05$.

	Predictor	*B*	SE (*B*)	*t*(399)	*p*
Main Effects:	Block 1	0.14	1.00	0.14	.89
	2	-0.58	1.01	-0.58	.56
	3	0.40	1.01	0.40	.69
Interactions:	Block 1 x Flow x Study 1	-4.29	1.54	-2.79	.01
	2 x Flow x Study 1	-2.53	1.59	-1.59	.11
	3 x Flow x Study 1	-1.55	1.60	-0.97	.33
	Block 1 x Flow x Study 2	-3.51	1.54	-2.28	.02
	2 x Flow x Study 2	-1.32	1.57	-0.84	.40
	3 x Flow x Study 2	-1.64	1.42	-1.15	.25
	Block 1 x Flow x Study 3	3.87	1.67	2.31	.02
	2 x Flow x Study 3	2.76	1.67	1.65	.10
	3 x Flow x Study 3	2.77	1.67	1.65	.10

Table 1. Predicted ΔPEP from Baseline, Model 3

Note: Flow scores have been standardized. Block and Study factors represent dummy-codes. Values in column *B* are unstandardized coefficients. Values in column SE (*B*) represent the standard error for the coefficient in that row.

3.4 Discussion

We tested cardiac PEP as a potential sympathetic nervous system marker of flow while undergraduate students gambled on authentic EGMs situated in a laboratory environment. We examined whether PEP changes were associated with EGM use, the stability of these levels over time, and their associations with self-reported flow, using multilevel regression models that accounted for the nested data structure. We did not observe significant change in PEP from the pre-task baseline to gambling. When we examined the interaction between task block and flow on PEP during gambling, we found that self-reported flow was associated with decreases in PEP (indicating *increased* sympathetic nervous system activity) during Block 1 (the first five minutes of gambling). When we explored this interaction within the three studies, we found opposing relationships between block and flow on ΔPEP. Studies 1 and 2 showed results consistent with Model 2: higher self-reported flow states during gambling were associated with greater decreases in PEP during Block 1 (but not Blocks 2 or 3). In Study 3, flow was associated with increased PEP (i.e. reduced sympathetic activity) and again, this effect was only statistically significant during Block 1. Taking these results together, it appears that early physiological responses to EGM use were related to increases in participants' subsequent flow ratings. We have thus found tentative support for an association between subjective flow and fluctuations in sympathetic nervous system activity. Crucially, however, the direction of this effect may depend on particular aspects of the task procedure.

It is worth speculating on why the observed interactions with flow were limited to the first five minutes of gambling. As our flow ratings were taken at the end of the session in Studies 1 and 3, this firstly indicates that participants' early experiences of the EGM are particularly important in accounting for variability in later flow ratings (a kind of primacy effect). These results further indicate that the initial physiological response to EGM use is an important factor in determining whether the session produces flow overall. Perhaps early experiences that produce physiological change increase the likelihood that gamblers will experience flow. In future research, it would be fruitful to take multiple flow measurements within a prolonged EGM gambling session, to characterize the subjective time-course, although such designs are challenging due to the potential for distractors to impair flow.

One possible explanation for the opposing results across the three studies is the social manipulation present in Study 3. Participants in that experiment were made aware that they may be gambling alongside other participants, and this may have impacted either their physiological response or experience of flow while gambling. Further, the gambling sessions in Study 1 (which saw the largest effect at Block 1) were conducted without an experimenter present in the room (in order to minimize any observer effects on risk-taking; Rockloff & Dyer, 2007; Rockloff, Greer, & Fay, 2011). Thus, participants' physiological responses to the gambling task may have been moderated by these social factors, either of researchers or other participants. Alternatively, our effects could be related to participants in each study employing different betting strategies. This necessarily affected the rate of reinforcement in these studies, and may have also had an impact on self-reported flow state (Murch & Clark, 2019b). Consistent with past findings, we found the highest levels of flow in Study 1, which employed a 40-line bet strategy to achieve high rates of reinforcement (Livingstone & Woolley, 2008; Templeton et al., 2015). Study 3 employed a smaller, 20-line strategy, and Study 2 compared several bet strategies that varied the number of lines bet, either 1, 5, or 20. Thus, if there is a real relationship between PEP and flow during EGM use, it may depend on additional factors that we could not systematically control in this aggregated analysis.

When not accounting for flow, we observed no significant change in PEP while gambling. Previous work has typically inferred sympathetic arousal from increases in mean heart rate during gambling, including on EGMs (Anderson & Brown, 1984; Coventry & Constable, 1999; Coventry & Hudson, 2001; Coventry & Norman, 1997; Griffiths, 1993). However, the physiology of heart rate change is complex, and affected by both branches of the autonomic nervous system (Cacioppo et al., 2007). Decreases in vagal tone while gambling (Murch et al., 2017; Murch & Clark, 2019), could potentially increase heart rate while sympathetic arousal remains constant, accounting for past results. A separate possibility is that heart rate effects did reflect sympathetic arousal in past experiments, but our laboratory environment or PEP measure may have lacked the sensitivity needed to detect a sympathetic response here.

Our findings are preliminary and intended to stimulate further enquiry; they have several important limitations. First, the three study protocols differed in numerous ways, and it is possible that methodological differences drove the disparate pattern of results. Second, the laboratory environment may have attenuated physiological reactivity. EGM gambling is regarded as an appetitive psychological challenge that involves intense audiovisual stimuli, motor actions and monetary outcomes, but responses to EGM use may differ based on whether the device is situated in a gambling venue, or in a laboratory environment (c.f. Anderson & Brown, 1984). Third, participants were convenience-sampled from an undergraduate population and were not regular EGM users. This potentially diminished both physiological responses to the EGM task, and the level of flow that was reported. Fourth, participants were men, because practical application of our PEP methods precluded the recruitment of women. Fifth, the GEQ Flow scale is unidimensional, focusing on absorption states, and other measures may provide insight into different aspects of the flow state (e.g. Jackson & Eklund, 2002). Finally, the block-by-flow-by-study analytic approach was exploratory, and the available data could not clarify why opposing effects were observed between the studies. Our preliminary conclusion is that cardiac sympathetic nervous system responses early in an EGM gambling session may affect subsequent ratings of flow for that session. However, follow-up studies should be undertaken in an attempt to replicate and clarify this effect.

Chapter 4: Zoned In or Zoned Out? Investigating Immersion in Slot Machine Gambling using Mobile Eye Tracking

4.1 Introduction

Immersion is a feeling of intense focus on a particular activity that reduces attention to competing goals and stimuli. Although viewed as desirable in many occupational and recreational contexts (Csikszentmihalyi, 2014), immersion in gambling activities is a robust predictor of problem gambling risk (Cartmill et al., 2015; Diskin & Hodgins, 1999, 2001; Dixon et al., 2018; Hopley & Nicki, 2010; Kofoed et al., 1997; Murch et al., 2017; Noseworthy & Finlay, 2009; Wanner et al., 2006). Electronic Gaming Machine (EGM, including modern slot machines) gambling may be especially immersive: an Australian survey found that 79% of gambling-related immersion experiences involved EGMs (Office for Problem Gambling, 2006).

Recently, authors have called for clarity in defining EGM immersion (Schluter & Hodgins, 2019). Previous work has characterized this state as 'dissociation', (Diskin & Hodgins, 1999; Gupta & Derevensky, 1998; Jacobs, 1986, 1988; Kuley & Jacobs, 1988; Wanner et al., 2006), the 'machine zone' (Oakes et al., 2018; Schüll, 2012), or 'flow' (Dixon et al., 2018; Trivedi & Teichert, 2017). These accounts all highlight a trance-like state that interferes with gamblers' awareness of peripheral events (e.g. people talking nearby) and the passage of time. However, the machine zone and dissociation (Jacobs, 1986; Schüll, 2012) constructs differ from flow by relying on a negative reinforcement mechanism: a sense of relief or escape from aversive realities that is provided by EGMs. Schüll (2012, p. 2, 74) argues that immersion supplants the desire to win money, becoming the sole motivation for gambling. By this account, gamblers could be relatively passive or ‘zoned out’ while gambling, showing little engagement with the game *per se*. In contrast, the flow account implies that these experiences emerge from skillful performance commensurate to the challenge or difficulty of the task (Csikszentmihalyi, 2014). This implies a ‘zoned in’ state in which task attention must be maintained to stay in the immersive ‘flow channel’(Csikszentmihalyi, 2014). By this account, gambling success necessarily remains a valued goal, the pursuit of which generates immersion.

Most research on EGM immersion has employed self-report measures, but a few behavioural studies tested whether immersed gamblers were less responsive to stimuli outside the game (Diskin & Hodgins, 1999, 2001; Murch et al., 2017). Crucially, this ‘dual task’ approach cannot assess the allocation of attentional resources to the game itself. Mobile eye tracking technology offers a means of exploring aspects of overt visual attention during gambling. Rogers and colleagues (2017) used mobile eye tracking to examine betting behaviour on fixed-odds betting terminals in British gambling shops, finding that problem gamblers spent more time looking at ‘amount-won’ messages. This finding complements laboratory studies in which people with gambling problems show visual biases towards gambling-related imagery (Brevers et al., 2011; Mcgrath, Meitner, & Sears, 2018).

Our primary aim was to ascertain whether EGM immersion is akin to being ‘zoned in’ or ‘zoned out’. These characterizations lead to testable and competing predictions regarding eye movements during the immersed state. If gamblers are ‘zoned in’, they should be relatively more attentive and reactive to the EGM display – especially to financial information displayed in the credit window, as the main indicator of ‘performance’ (albeit in a game of chance). If they are ‘zoned out’, gamblers should be relatively less attentive to their task performance, instead directing their eyes to the most stimulating parts of the display: the spinning reels.

We pre-registered[2] several hypotheses (based on a convenience-sampled pilot study, see 4.3.7), to arbitrate between these accounts using eye movement metrics during EGM gambling (Table 2). We hypothesized that immersed gamblers would look relatively more at the game's credit window and relatively less at the reels in an EGM gambling session. We interpret this behaviour as consistent with being 'zoned in'.

We examined whether immersed gamblers make more saccades and fewer blinks. We believe such results would be consistent with being 'zoned in', while the opposite pattern would indicate being 'zoned out'. Exploring these data further, we examined event-related fixations during different phases within each bet. We looked for relationships between EGM outcomes and immersion. Lastly, we examined whether immersion was related to gambling-related cognitions, negative affect (Dixon et al., 2018), or symptoms of adult Attention Deficit Hyperactivity Disorder (ADHD; Breyer et al., 2009; Murch & Clark, 2019; Waluk et al., 2016) that have correlated with immersion in past research.

Independent Variable	**Dependent Variable**	**Hypothesized Relationship**	**Indicates**
Immersion	Ratio of dwell time on credit window AOI over dwell time on reels AOI *	+	Zoning in
	Ratio of fixations on credit window AOI over fixations on reels AOI *	+	Zoning in

[2] Pre-registration: https://aspredicted.org/k4ty9.pdf

	Number of saccades	+/-	Zoning in (+) or Zoning out (-)
	Number of blinks	+/-	Zoning in (-) or Zoning out (+)
	Gambling-related cognitions (GRCS, all subscales)	+/-	Zoning in (+) or Zoning out (-)
	Past-week depression, anxiety and stress (DASS, all subscales)	+/-	Individual risk for immersion
Problem gambling (PGSI)	Ratio of dwell time on credit window AOI over dwell time on reels AOI *	+	Potential covariate for immersion
	Ratio of fixations on credit window AOI over fixations on reels AOI *	+	Potential covariate for immersion
Adult ADHD symptoms (ASRS)	Dwell time and fixations on the credit window AOI	+/-	Potential covariate for immersion
	Dwell time and fixations on the reels AOI	+/-	Potential covariate for immersion

Table 2. Pre-registered and exploratory hypotheses.

Note: Pre-registered hypotheses were based on the results of a convenience-sampled pilot study (see 4.3.7). * = Primary pre-registered hypothesis.

4.2 Methods

4.2.1 Participants

Experienced EGM gamblers were recruited through craigslist.ca. Respondents (N = 245) completed an online eligibility screening. We recruited respondents age 19 or older, who reported EGM use (including online) in the past 12 months, and who reported normal vision, using contact lenses, or using glasses with a prescription strength between -4 and +4 diopters.

We excluded respondents who reported recent or severe traumatic brain injury, neuropsychiatric or ophthalmic disease, or current use of psychotropic medications. Because the experiment involved authentic EGM gambling, we excluded individuals who scored 8 or higher on the Problem Gambling Severity Index (Ferris & Wynne, 2001).

Participants (N = 63) were paid $20 CAD for attending a 1-hour test session, and received $0-20 as an additional bonus from the EGM. Ten participants were excluded from analysis: seven due to poor quality eye tracking data, one due to a video capture error that made behavioural data unavailable, and two who reported past-year EGM use on the eligibility screen but none on test day. All experimental protocols were approved by UBC's research ethics board.

4.2.2 Questionnaires

After providing written consent, participants completed the Problem Gambling Severity Index (Ferris & Wynne, 2001), a 9-item scale that probes symptoms of problem gambling in the past year. A score of 8 or higher indicates high risk for problem gambling, and such participants were excluded from the EGM procedure. In our analyses, the PGSI was treated as a continuous measure.

Participants completed the Short-Form Adult Attention Deficit Hyperactivity Disorder (ADHD) Self-Report Scale (ASRS; Kessler et al., 2005). The ASRS contains six items and probes adult ADHD symptomatology over the past six months. Responses were given on a 5-point Likert scale ranging from "Never (0)" to "Very often (4)." Items were summed at equal weight for scoring (see: 3). Several studies have linked adult ADHD and problem gambling (Breyer et al., 2009; Groen, Gaastra, Lewis-Evans, & Tucha, 2013; Waluk et al., 2016).

The Gambling-Related Cognitions Scale (GRCS; Raylu & Oei, 2004) includes 23 items grouped into five factors that probe gamblers' beliefs: interpretive bias (e.g. "relating my winnings to my skill and ability makes me continue gambling"), illusion of control (e.g. "specific numbers and colours can help increase my chances of winning"), predictive control (e.g. "I have some control over predicting my gambling wins"), gambling expectancies (e.g. "having a gamble helps reduce tension and stress"), and perceived inability to stop gambling (e.g. "I will never be able to stop gambling"). Responses were given on a 7-point Likert scale ranging from "Strongly disagree" to "Strongly agree." Six participants failed to provide a response to a single item on this scale. The missing items were half-mean imputed using the affected subscales, following the recommendations of Bell and colleagues (Bell & Fairclough, 2014).

The Depression Anxiety and Stress Scale short-form (DASS; Lovibond, P & Lovibond, S, 1995) contains 21 items probing past-week experiences. Responses were scored on a 4-point Likert scale ranging from "Did not apply to me at all (0)" to "Applied to me very much, or most of the time (3)." Mood disorders are comorbid with problem gambling and have been linked to EGM immersion (Dixon et al., 2018; Petry et al., 2005). One participant was missing a single item. This cell was half-mean imputed using the mean of the affected subscale.

The Canadian Problem Gambling Index (Ferris & Wynne, 2001) includes an expansive list of gambling activities, and asks respondents to indicate how often they participated in each over the past year. Responses were scored on an 8-point Likert scale ranging from "Never" to "Daily." It was used to verify the consistency of participants' self-reported EGM use over the past year. Two participants were thus excluded.

Following the EGM task, participants completed an immersion questionnaire, which is a concatenation of the Dissociation Questionnaire (Diskin & Hodgins, 1999; Jacobs, 1988) and Flow subscale of the Game Experience Questionnaire (IJsselsteijn et al., 2013; Poels & Kort, 2007). Seven items (e.g. "I lost track of time while playing the slot machine," "I felt completely absorbed,") were rated on a 5-point Likert scale ranging from "Very slightly or not at all (0)" to "Extremely (4)". Mean scores were calculated and reliability analyses were performed. We have previously employed this measure (Murch & Clark, 2019b).

4.2.3 Procedure

The EGM session was carried out in our laboratory, which houses four genuine EGMs, balancing the ecological validity of real EGMs with the situational control afforded by a laboratory environment (Murch & Clark, 2018; Stewart et al., 2002). Participants were endowed $40 to play "Buffalo Spirit" (Scientific Games Co., Las Vegas, NV). The game's hold was 11% (i.e. at infinite spins, the game pays out $0.89 for every dollar wagered). Bets were constrained to $0.40, in order that participants were less likely to look away from the screen to re-configure their bet. A maximum-paylines (40), minimum-stake ($0.01) strategy was selected because it is popular among regular gamblers, and maximizes the reinforcement rate (Livingstone & Woolley, 2008; Templeton et al., 2015). Buffalo Spirit includes a 'free spin' bonus game that is triggered by the appearance of three specific symbols. During free spins, the game plays without user input, and winnings accrue in the Win window. Participants were not informed of the 20-minute duration but were instructed that any profits over the initial $40 endowment would be paid as a bonus, to a maximum of $20.

4.2.4 Apparatus

Natural gaze behaviour was recorded in real-time from both eyes using mobile eye tracking glasses (SMI, Teltow, Germany). Data were recorded at 60 Hz to a Samsung Galaxy Note 4 affixed to the back of the participant's seat (Figure 6A). The glasses were 3-point calibrated using the top left, top right, and bottom left symbols on the EGM screen (Figure 6b). Participants were allowed to seat themselves at a comfortable distance from the EGM. Since SMI Eye Tracking Glasses preclude the use of prescription glasses, some participants selected approximate corrective lenses from the SMI corrective lens kit.

In order to derive the time series of EGM events, we recorded and analyzed the EGM screen during each session. The screen was duplicated using an HDMI Splitter (OREI, Skokie, IL), and passed via AV.IO Video Grabber (Epiphan, Palo Alto, CA) to a video capture computer running Debut 3.01 recording software at 60Hz (NCH, Greenwood Village, CO). These videos were processed using an image recognition program built in Python 2.7 using OpenCV2 (Intel, Santa Clara, CA). The output was a time series of game events for each participant.

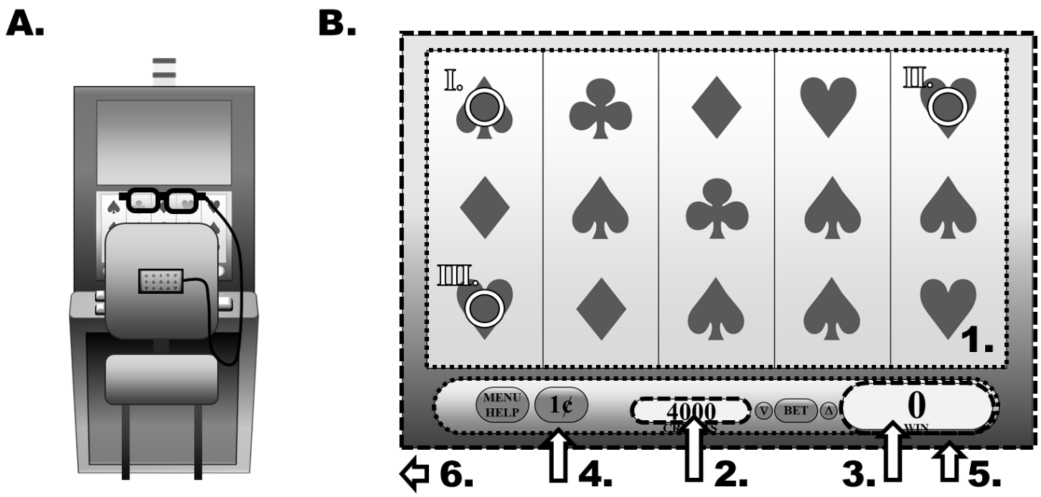


Figure 6. Task apparatus.

Note: A) EGM and mobile eye tracking apparatus without participant. B) Game screen with calibration points (I-III) and areas of interest (1-6). 1) reels, 2) credit window, 3) win window, 4) menu bar, 5) game border, 6) game periphery.

4.2.5 Data Processing

Eye movement data were mapped to a reference image based on the screen layout of the EGM (Figure 6). Six mutually-exclusive areas-of-interest (AOIs) were defined on the reference image: 1) reels, 2) credit window, 3) win window (a larger window to the right of the credit window that reads zero unless a payout is being delivered), 4) menu bar (which displays information about the game denomination, and bet size), 5) game border (the remaining screen area not included in other AOIs), and 6) game periphery (the entire area outside the game screen). Session-wise statistics were exported from BeGaze alongside the raw reference image data. Blinks and saccades were defined automatically in BeGaze. Saccade amplitude was defined as the average distance (pixels) between the start and end position of all saccades. Dwell time was defined as the percentage of task time spent fixating on a given AOI. Fixations were defined as the number of times visual intake was recorded in an AOI following a blink or saccade, divided by task time. Gaze data normalized by AOI size are presented in Table 4 for descriptive purposes. Analyses were performed on the non-normalized data. The ratio of dwell time (or fixations) at the credit window to the reels was calculated. Data were analyzed in R (Fox & Weisberg, 2011; JASP Team, 2019; Peng, 2019; R Core Team, 2018; Wei & Simko, 2017). Descriptive data are reported with median, minimum, and maximum values where skew was present. Non-event-related hypotheses were tested using bivariate regression. Reported confidence intervals were bootstrapped with 5,000 iterations (A. F. Hayes, 2013).

4.2.6 Event-Related Analyses

To further explore whether fixation patterns might be affected by specific in-game events and immersion, we derived a time series of on-screen game events for trial-by-trial analyses. We analyzed data at three phases within each trial: reel spin, audiovisual feedback (where reinforcement is delivered paired with some sound and animation), and spin initiation latency (the delay between the feedback ending and the participant initiating the next spin, Figure 7). Spin outcomes were categorized into wins, losses, free spin bonuses, and losses-disguised-as-wins (Dixon et al., 2010). Of these, loss trials are unique in entailing a spin initiation latency phase with no preceding feedback phase since no credits are awarded. The music and spins in a free spin bonus continue without pausing for user input, so we treated them as a single feedback phase. Our use of a genuine EGM meant that we could not control how many outcomes of each type occurred, or the order in which they appeared. In total, 20,749 events were recorded for each model.

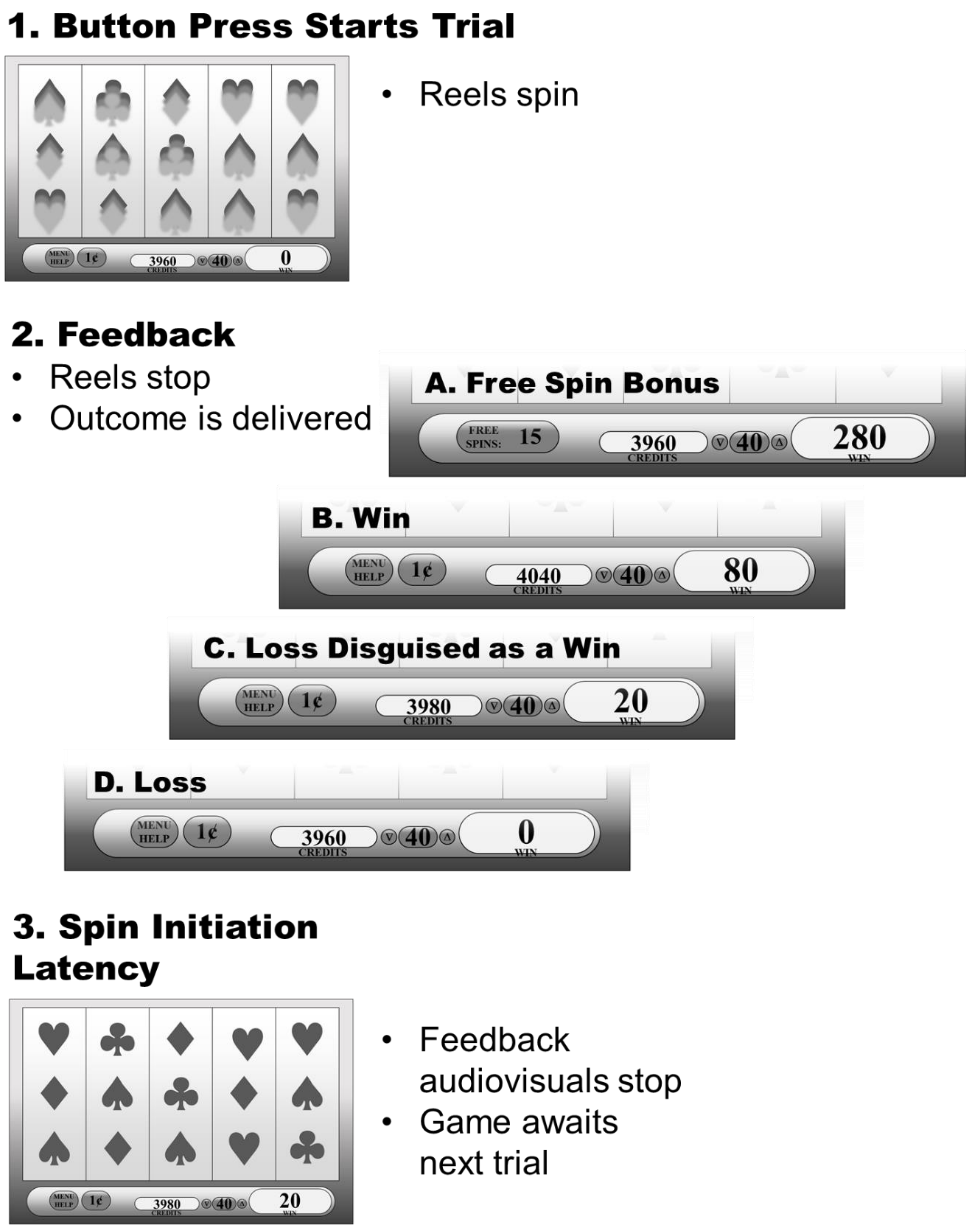


Figure 7. Trial phases and outcome types.

Note: Each trial proceeds from 1 - 3 with only one of 2A - 2D occurring. Feedback phase 2A encompasses 15 or more continuous free spins and any feedback that occurred after they were completed. There is no audiovisual feedback in phase 2D.

For each trial phase, we recorded a trial number, duration (seconds), outcome type (loss, win, losses-disguised-as-wins or free spin bonus; reel spins were the reference category), and the proportion of that phase spent fixating on the reels, credit window and win window. Data inspection showed that many phases were spent fixating on only one AOI, polarizing the data (i.e. one AOI value equaled one, and the rest zero). To address this, all non-zero event-related eye movement data were converted to 1 and data were analyzed in three fixed-effects logistic regressions (Allison, 2012; Chu, Limbrick-Oldfield, Murch, & Clark, 2018; Tobias-Webb et al., 2017) that tested the likelihood the reels, credit window or win window were fixated-on during a given phase. In a fixed-effects model, each subject is treated as their own control, and model estimates reflect increases or decreases in the likelihood that a given AOI is fixated-on during a given trial phase. With this approach, if a participant does not experience a particular outcome type (e.g. a free spin bonus), they do not contribute to the relevant estimate. In this way, there is no need to impute missing data or exclude participants.

Separate fixed-effects logistic regressions were carried out on the reels, credit window and win window. Odds ratios were computed. Models were assessed for multicollinearity and violations of linearity (A. Field, 2012). The duration of trial phases appeared to show evidence of linear, quadratic, and cubic trends for certain models. Non-linear trends were not included in the model as they were not expected or clearly explicable, and their inclusion could thus capitalize on error variance in the model. Standardized residuals were calculated and plotted against the predictor variables. No relationships were apparent. Analysis scripts and all relevant data are available online[3].

[3] https://dataverse.scholarsportal.info/dataset.xhtml?persistentId=doi:10.5683/SP2/GSOMLU

Models were composed first of participant (fixed factor), trial number (centered at one), and phase duration (grand-mean centered). These factors accounted for incidental variance between participants, across the span of the task, and as a result of some outcomes (e.g. bonus features) being systematically longer in duration. We then added the dummy-coded outcome phases. Predictions made by these models thus reflect differences in the likelihood of fixating on a given AOI during a particular outcome phase, compared to when the reels are spinning. Lastly, for outcome phases that significantly differed from reel spins, immersion was tested as an interaction term. Non-significant interaction terms were backwards-eliminated, increasing these exploratory models' parsimony and statistical power, but also the risk of type 1 error. Bootstrapping these data produced instances of complete separation, so not all confidence intervals in Table 5 were bootstrapped.

4.2.7 Pilot Study and Pre-Registration

A convenience-sampled pilot study was conducted to direct the hypotheses of this experiment. The inclusion and exclusion criteria were identical to the follow-up study, except that we did not require participants to report past-year EGM use. Thirty-three participants were recruited, though six (18.18%) were excluded due to incomplete data or equipment failure. The pilot sample thus consisted of 27 individuals (median age = 24, range = 19 – 67, 9 males, 18 females). Pilot participants did not complete the Gambling-Related Cognitions Scale (GRCS), the Depression Anxiety and Stress Scale (DASS), or some parts of the Canadian Problem Gambling Index. Procedures were otherwise identical to the main experiment.

In general, pilot participants reported few problem gambling symptoms: 19 (70.37%) gave a Problem Gambling Severity Index (PGSI) score of 0, five (18.52%) scored 1-2, and three

(11.11%) scored 3-7. The median ASRS score was 9 (range = 4 – 17). The median immersion score was 0.86 out of 4 (range = 0.14 – 2.71). The median test session ended with $26.40 (range = $0 – $137.15) remaining of the initial $40 endowment. For the 8 (29.63%) participants who ran out of credit before 20 minutes of gambling had been recorded, the median session lasted 15.58 minutes (range = 12.74 – 20).

Pilot participants spent 71.9% of the task looking at the reels (SD = 8.30; Table 3), but often looked at other game features as well. 5.6% (SD = 3.50) of task time was spent looking at the credit window, 3.1% (SD = 1.84) at the win window, and only 0.9% (SD 1.08) on anything off-screen.

	% Dwell Time	*Normalized Dwell Time*	*Fixations / Minute*	*Normalized Fixations*
Reels	71.86 (8.30)	1.02 (0.12)	110.95 (24.46)	1.58 (0.35)
Credit window	5.59 (3.50)	5.37 (3.36)	10.39 (5.99)	9.98 (5.76)
Win window	3.14 (1.84)	1.26 (0.74)	6.06 (3.60)	2.43 (1.44)
Menu bar	4.99 (2.82)	0.60 (0.34)	9.34 (4.82)	1.13 (0.58)
Game border	5.71 (2.32)	0.32 (0.13)	5.58 (2.91)	0.31 (0.16)
Game periphery	0.90 (1.08)	∞	2.19 (2.38)	∞

Table 3. Eye movement metrics by area of interest in the pilot sample.

Note: % Dwell time refers to the mean percentage of the session spent fixating on each AOI. Fixations / Minute refers to the number of fixations at each AOI per minute of the session. Values represent the mean (SD). Normalized data have been divided by the percentage of the screen occupied by the AOI. The game periphery is infinite in normalized columns because it exists off screen.

There was a significant positive relationship between immersion and dwell time at the credit window AOI (B = 2.06, $t(25)$ = 2.19, p = .038, R^2 = .16, 95% CI [-0.43, 4.66]), as well as a significant negative relationship between immersion and dwell time at the reels AOI (B = -5.23, t(25) = -2.38, p = .025, R^2 = .18, 95% CI [-9.38, 1.19]). This relationship, reflecting a shift in attention from the reels to the credit information, could be captured singularly as a correlation between immersion and the ratio of dwell time to the credit window AOI over the reels AOI (B = 0.04, t(25) = 2.62, p = .015, R^2 = .22, 95% CI [.0004, .09]). For visual fixations, there was a positive correlation between self-reported immersion and fixations at the credit window AOI (B = 3.73, t(25) = 2.34, p = .028, R^2 = .18, 95% CI [-0.50, 8.51]), but no significant relationship for the reels AOI (B = -9.04, t(25) = -1.30, p = .205, R^2 = .06, 95% CI [-20.19, 3.29]). Nevertheless, the ratio measure (credit window AOI : reels AOI) was also significantly correlated with immersion (B = 0.05, t(25) = 2.71, p = .012, R^2 = .23, 95% CI [-0.002, 0.10]).

Eye movements to the credit window AOI were negatively correlated with ASRS (dwell time: B = -0.47, t(25) = -2.36, p = .027, R^2 = .18, 95% CI [-0.88, -0.16]; fixations: B = -0.80, t(25) = -2.34, p = .027, R^2 = .18, 95% CI [-1.50, -0.32]). These relationships were not mirrored with significant positive relationships at the reels AOI (dwell time: B = -0.14, t(25) = -0.26, p = .797, R^2 < .01 , 95% CI [-1.18, 1.19]; fixations: B = 0.15, t(25) = 0.10, p = .923, R^2 < .01 , 95% CI [-2.72, 3.27]). If replicated in the main experiment, these trends could impact our ability to interpret hypotheses concerning immersion and visual attention.

The main experiment sought to test the reliability of these relationships, in a larger sample composed of experienced gamblers. Sample size was based on power calculations using the effect size for the correlation between immersion and the ratio of dwell time to the credit window relative to the reels AOI (one-tailed). For the primary hypothesis, tests on ratios were favoured to mitigate type-1 error rate. We pre-registered the hypotheses and methods on aspredicted.org[4].

4.3 Results

After data cleaning, the final sample included 53 participants (84.13%, 32 males, 21 females) with a median age of 30 (range = 19 – 64). Most participants (n = 34, 64.15%) reported casino gambling one to five times in the past year. Seventeen (32.08%) reported visiting casinos more than five times. Two (3.77%) reported gambling on EGMs online, but not in a casino. The modal (n = 23, 43.40%) PGSI score was 0; 17 (32.10%) scored 1 - 2 (low-risk), and 13 (24.53%) scored 3 - 7 (moderate-risk).

The median participant made 179 spins (range = 117 – 233) during the task. Losses were the most common outcome (median = 140, range = 95 – 190). Losses-disguised-as-wins (median = 18, range = 10 – 33) occurred about as often as wins (median = 17, range = 8 – 28). The median participant saw one free spin bonus round (range = 0 – 4), and 14 participants (26.32%) did not experience any of the 58 bonuses that occurred. Sixteen participants (30.19%) finished the session in profit, and the median participant finished the task with \$17.20 (range = \$0 – \$109.40) of their \$40 endowment remaining. Among the 18 participants (33.96%) who ran out of credit before completing a 20-minute session, the median session length was 16.28 minutes (range = 11.00 – 20.00).

The reels AOI accounted for the most dwell time (mean = 71.46 %, SD = 10.06), but participants also dwelt on the credit window (mean = 4.45%, SD = 2.98) and win window (mean

[4] https://aspredicted.org/k4ty9.pdf

= 3.07%, SD = 1.72). Only 0.97% (SD = 1.97) of dwell time occurred off screen (see Table 4 and Figure 8). When these values were normalized to account for the size of each AOI, a clear bias towards the credit window was observed.

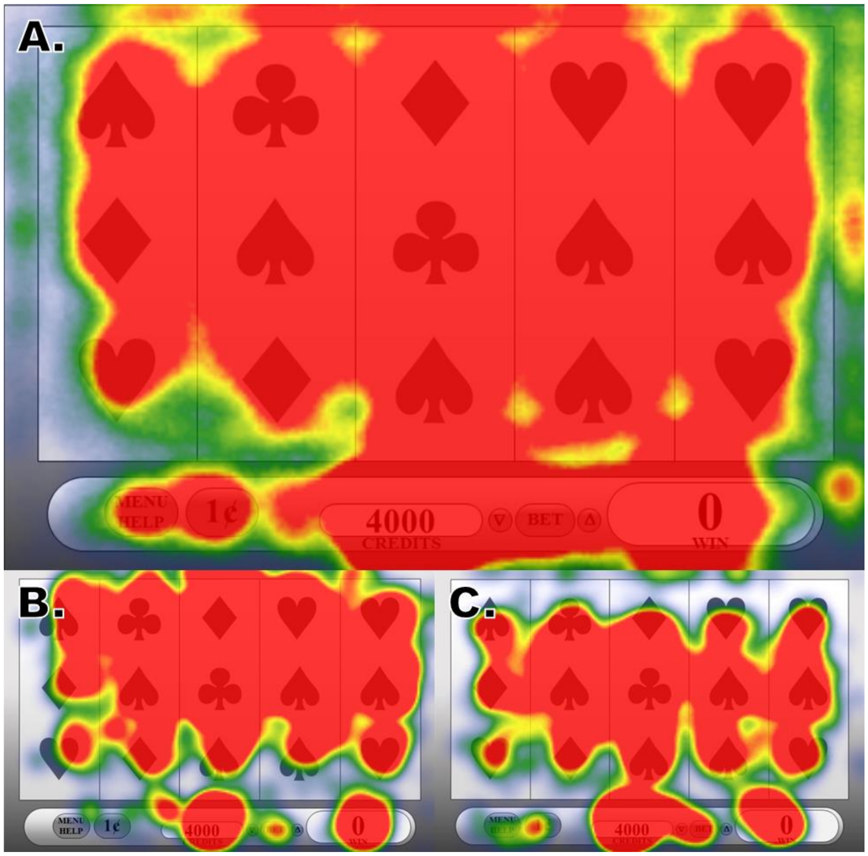


Figure 8. Heatmap of fixations to the EGM screen.

Note: A) Heatmap of all participants across the full EGM task. B) Full-task heatmap for a participant who reported low immersion. C) Full-task heatmap for a participant who reported high immersion. Warmer colours indicate greater time spent fixating on that point.

4.3.1 Exploratory Hypotheses

Cronbach's alpha for the immersion questionnaire was .75, an improvement over the Dissociation Questionnaire alone (.60). The median immersion score was 1.14 out of 4 (range =

0.14 – 2.86). Immersion was significantly related to PGSI (*B* = 1.02, *t*(51) = 2.62, *p* = .012, R^2 = .12, 95% CI [0.16, 1.77]), as well as several GRCS subscales. Among them, the subscales for illusion of control (*B* = 0.73, *t*(50) = 3.18, *p* = .003, $R^2_{partial}$ = .17, 95% CI [0.30, 1.23], PGSI included as a covariate) and predictive control (*B* = 0.65, *t*(50) = 2.47, *p* = .017, $R^2_{partial}$ = .11, 95% CI [0.10, 1.20]; additional results in 4.4.4).

The median participant blinked 6.92 times per minute (range = 0.35 – 52.66) and made 147.57 saccades per minute (range = 86.04 – 186.72). Immersion was associated with a greater total number of saccades during the EGM task (*B* = 13.40, *t*(51) = 2.95, *p* = .005, R^2 = .15, 95% CI [5.17, 21.15], Figure 9A). The number of saccades was not related to saccade amplitude (*B* = -0.08, *t*(51) = -0.49, *p* = .629, R^2 < .01 , 95% CI [-0.38, 0.29]). Additional results are discussed in section 4.4.4.

	% Dwell Time	*Normalized Dwell Time*	*Fixations / Minute*	*Normalized Fixations*
Reels	71.46 (10.06)	1.02 (0.14)	117.10 (21.05)	1.67 (0.30)
Credit window	4.45 (2.98)	4.28 (2.86)	8.67 (4.99)	8.33 (4.80)
Win window	3.07 (1.72)	1.23 (0.69)	5.79 (2.63)	2.32 (1.05)
Menu bar	6.15 (2.77)	0.74 (0.34)	12.48 (5.29)	1.51 (0.64)
Game border	6.59 (3.51)	0.37 (0.20)	7.32 (5.27)	0.41 (0.29)
Game periphery	0.97 (1.97)	∞	2.20 (3.83)	∞

Table 4. Eye movement metrics by area of interest.

Note: % Dwell time refers to the mean percentage of the session spent fixating on each AOI. Fixations / Minute refers to the number of fixations at each AOI per minute of the session. Values represent the mean (SD). Normalized data are provided here for descriptive purposes. The data have been divided by the percentage of the screen occupied by the AOI. The game periphery is infinite in normalized columns because it exists off screen.

4.3.2 Pre-Registered Primary Hypotheses

The pre-registered hypotheses were partially supported. Consistent with our pilot results, a higher ratio of dwell time to the credit window AOI relative to the reels AOI was associated with higher levels of self-reported immersion during the EGM task (B = 2.98, t(51) = 1.68, p = .049 one-tailed, R^2 = .05, 95% CI_{Lower} = 0.59, Figure 9B). The overall number of fixations on the different AOIs (credit window/reels) was not related to higher immersion (B = 2.39, t(50) = 1.23, p = .112 one-tailed, R^2 = .03, 95% CI_{Lower} = -0.59). Neither dwell time ratio (B = 0.30, t(50) = 0.06, p = .478 one-tailed, R^2 < .01, 95% CI_{Lower} = -7.69), nor fixation ratio (B = -0.35, t(50) = -0.06, p = .476 one-tailed, R^2 < .01 , 95% CI_{Lower} = -8.43) were significantly related to PGSI.

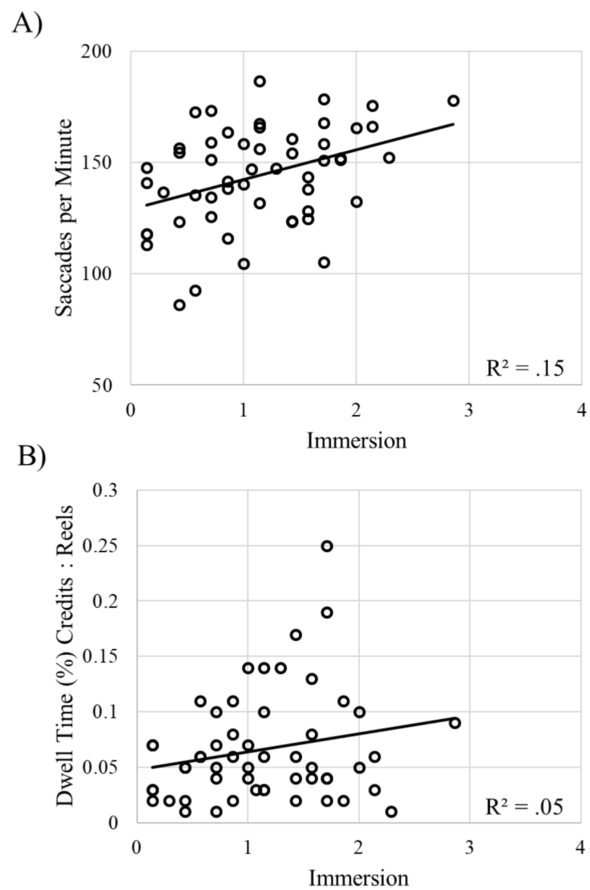


Figure 9. Relationships between eye movements and immersion.

Note: Immersion score correlated with (A) the number of saccades per minute, and (B) dwell time at the credit window AOI divided by dwell time at the reels AOI. X-axis represents average score on 7-item immersion questionnaire. Each data point represents the mean of one participant. Line represents best-fit linear trend.

4.3.3 Event-Related Analyses

4.3.3.1 Reels model

Fixations on the different regions of the screen varied by trial phase and outcome. The likelihood of fixating on the reels was lower during every outcome phase than it was during the reel spin (Table 5A, Figure 10).

4.3.3.2 Credit window model

Comparing winning outcome phases to reel spins, participants were less likely to fixate on the credit window during win feedback (OR = 0.58, Table 5B, Figure 10), but more likely during the ensuing spin initiation latency (OR = 1.46). During bonus feedback, fixations on the (then inactive) credit window were much less likely (OR < 0.01), but then were more likely during spin initiation latencies (OR = 4.32). On losses-disguised-as-wins, participants were less likely to fixate on the credit window during both feedback (OR = 0.32) and spin initiation latency (OR = 0.78).

4.3.3.3 Win window model

Comparing winning outcomes to reel spins, participants were more likely to look at the win window during both feedback (OR = 1.27, Table 5C, Figure 10) and spin initiation latency (OR = 6.56). For losses-disguised-as-wins, fixations were less likely during feedback (OR = 0.30), but more likely during spin initiation latency (OR = 1.99). During spin initiation latencies for bonuses, fixations on the win window were more likely (OR = 7.83).

4.3.3.4 Immersion interactions

Self-reported immersion interacted significantly with some outcomes in the win window and reels models. Higher-immersion participants were less likely to fixate on the reels during losses (OR = 1.42, Table 5A, Figure 10), and feedback for losses-disguised-as-wins (OR = 1.89), as well as spin initiation latencies for wins (OR = 1.97) and losses-disguised-as-wins (OR = 1.77). Higher-immersion participants were less likely to fixate on the win window during bonus feedback (OR = 0.14, Table 5C), as well as spin initiation latencies for wins (OR = 0.66), and losses-disguised-as-wins (OR = 0.72).

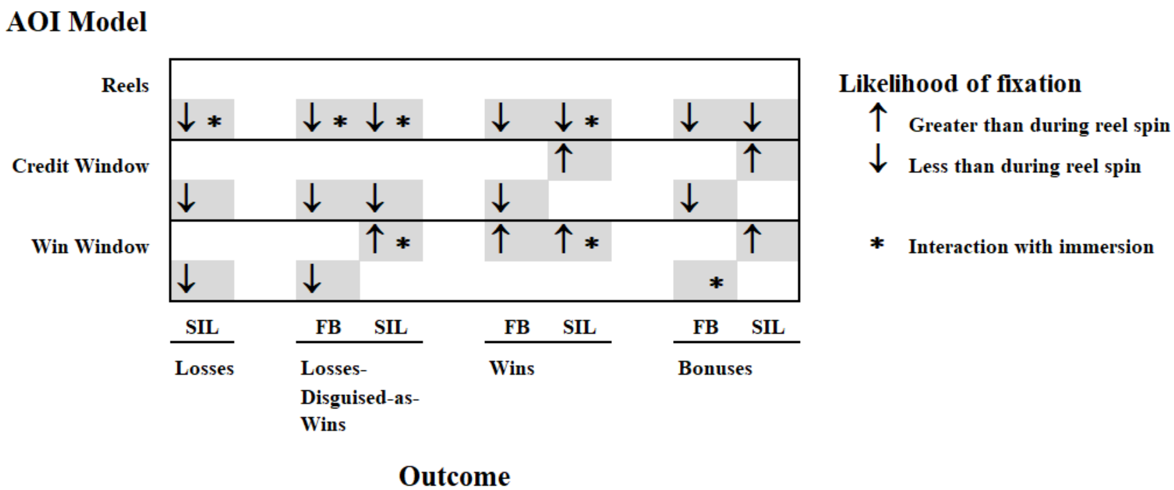


Figure 10. Direction of relationships in event-related models.

Note: Results are relative to the reference category, reel spins. Losses do not have audiovisual feedback. FB = Feedback phase, SIL = Spin Initiation Latency phase.

		AOI Model											
		A) Reels			R^2_N = .89	**B) Credit Window**			R^2_N = .50	**C) Win Window**			R^2_N = .66
	Factor	*OR*	[95% CI]	Z	*p*	*OR*	[95% CI]	Z	*p*	*OR*	[95% CI]	*Z*	*p*
	Trial Number	0.99	[0.99, 0.99]	-19.87	<.001	1.00	[1.00, 1.00]	-2.98	.003	1.00	[1.00, 1.00]	-3.33	<.001
	Event Duration	1.17	[1.03, 1.32]	4.99	<.001	1.17	[1.14, 1.19]	18.69	<.001	1.16	[1.14, 1.19]	17.96	<.001
Outcomes:	Reel spin (Reference)												
	Loss SIL	0.30	[0.21, 0.43]	-5.31	<.001	0.55	[0.50, 0.60]	-13.42	<.001	0.45	[0.40, 0.51]	-13.87	<.001
	Win feedback	0.41	[0.28, 0.60]	-4.38	<.001	0.58	[0.46, 0.71]	-5.32	<.001	1.27	[1.05, 1.56]	2.39	.017
	Win SIL	0.05	[0.03, 0.08]	-10.18	<.001	1.46	[1.26, 1.70]	4.63	<.001	6.56	[5.00, 8.62]	11.99	<.001
	LDW feedback	0.11	[0.06, 0.19]	-7.19	<.001	0.32	[0.25, 0.40]	-9.77	<.001	0.30	[0.22, 0.42]	-7.47	<.001
	LDW SIL	0.23	[0.12, 0.42]	-3.94	<.001	0.78	[0.67, 0.91]	-2.92	.004	1.99	[1.46, 2.71]	3.87	<.001
	Bonus feedback	<0.01	[0.00, 0.00] [A]	-5.61	<.001	<0.01	[0.00, 0.01] [A]	-8.46	<.001	0.09	[0.01, 1.47] [A]	-1.69	.091
	Bonus SIL	0.02	[0.01, 0.03] [A]	-12.32	<.001	4.32	[2.43, 7.70] [A]	4.98	<.001	7.83	[4.45, 13.78] [A]	7.14	<.001
Interactions:	Loss : Immersion	1.42	[1.23, 1.63]	2.46	.014								
	Win SIL : Immersion	1.97	[1.43, 2.72]	3.24	.001					0.66	[0.54, 0.80]	-3.48	<.001
	LDW feedback : Immersion	1.89	[1.39, 2.56]	3.00	.003								
	LDW SIL : Immersion	1.77	[1.21, 2.58]	2.19	.029					0.72	[0.58, 0.91]	-2.32	.020
	Bonus feedback : Immersion									0.14	[0.02, 0.91] [A]	-2.06	.039

Table 5. Fixed effects logistic regression models predicting AOI visitation for different outcome phases and states of immersion.

Note: Reported confidence intervals have been bootstrapped with 5000 iterations, except where denoted by [A]. *OR* = Odds Ratio, LDW = losses disguised as wins, SIL = Spin Initiation Latency, R^2_N = Nagelkerke's Coefficient of Determination. Non-significant interaction terms were backward-eliminated from the models in descending order of significance.

4.3.4 Additional Exploratory Results

Self-report measures. The median ASRS score was 10 out of 24 (range = 0 – 17). The median scores for the depression, anxiety and stress subscales were 6 (range = 0 – 32), 4 (range = 0 – 30) and 10 (range = 0 – 36), respectively. PGSI was significantly related to ASRS (B = 0.70, t(51) = 2.27, p = .028, R^2 = .09, 95% CI [0.06, 1.25]), DASS subscales for anxiety (B = 1.78, t(51) = 4.11, p < .001, R^2 = .25, 95% CI [0.78, 3.02]), and stress (B = 1.62, t(51) = 2.81, p = .007, R^2 = .13, 95% CI [0.34, 3.22]), but not depression (B = 0.81, t(51) = 1.29, p = .201, R^2 = .03, 95% CI [-0.38, 2.50]). DASS depression was not associated with immersion (B = 2.13, t(51) = 1.14, p = .260, R^2 = .02, 95% CI [-1.24, 5.65]). When PGSI was included as a covariate, neither anxiety (B = 1.01, t(50) = 0.73, p = .468, $R^2_{Partial}$ = .01, 95% CI [-1.94, 4.24]) nor stress (B = 3.56, t(50) = 2.01, p = .050, $R^2_{Partial}$ = .07, 95% CI [-0.97, 6.94]) were associated with immersion.

PGSI score was positively correlated with GRCS subscales for illusion of control (B = 0.24, t(51) = 3.04, p = .004, R^2 = .15, 95% CI [0.05, 0.49]), predictive control (B = 0.23, t(51) = 2.57, p = .013, R^2 = .11, 95% CI [0.03, 0.39]) and interpretive bias (B = 0.29, t(51) = 3.16, p = .003, R^2 = .16, 95% CI [0.09, 0.49]), but not gambling expectancies (B = 0.18, t(51) = 1.94, p = .058, R^2 = .07, 95% CI [-0.02, 0.35]) or inability to stop gambling (B = 0.10, t(51) = 1.99, p = .052, R^2 = .07, 95% CI [-.003, 0.23]). When we examined relationships between GRCS subscales and immersion, we included PGSI as a covariate. Immersion was significantly related to GRCS subscales for illusory control (B = 0.73, t(50) = 3.18, p = .003, $R^2_{partial}$ = .17, 95% CI [0.30, 1.23]), predictive control (B = 0.65, t(50) = 2.47, p = .017, $R^2_{partial}$ = .11, 95% CI [0.10, 1.20]), gambling expectancies (B = 0.66, t(50) = 2.39, p = .021, $R^2_{partial}$ = .10, 95% CI [0.06, 1.33]), and interpretive bias (B = 0.79, t(50) = 2.91, p = .005, $R^2_{partial}$ = .14, 95% CI [0.22, 1.34]) ¸but not perceived inability to stop gambling (*B* = 0.06, $t(50) = 0.42$, $p = .679$, $R^2_{partial} < .01$, 95% CI [-0.27, 0.38]).

Despite evidence in the pilot sample of a relationship between adult ADHD and fixations and dwell time on the EGM credit window, secondary hypotheses concerning the relationships between ASRS and dwell time on the credit window (*B* = -0.05, $t(51) = -0.50$, $p = .62$, $R^2 < .01$, 95% CI [-0.21, 0.12]), dwell time on the reels (*B* = 0.31, $t(51) = 0.98$, $p = .33$, $R^2 = .02$, 95% CI [-0.26, 0.92]), fixations on the credit window (*B* = -0.12, $t(51) = -0.76$, $p = .450$, $R^2 = .01$, 95% CI [-0.42, 0.20]), and fixations on the reels (*B* = -0.39, $t(51) = -0.59$, $p = .559$, $R^2 = .01$, 95% CI [-1.85, 1.00]), were not supported.

Behavioural measures. PGSI score was not significantly correlated with the number of saccades per minute during the EGM task (*B* = 0.75, $t(51) = 0.45$, $p = .653$, $R^2 < .01$, 95% CI [-2.64, 4.15]). The number of blinks per minute of the session was not correlated with PGSI (*B* = -1.05, $t(51) = -1.45$, $p = .152$, $R^2 = .04$, 95% CI [-2.55, 0.07]), or immersion (*B* = 1.28, $t(51) = 0.59$, $p = .558$, $R^2 = .01$, 95% CI [-2.88, 5.40]).

4.4 Discussion

We described ‘zoning in’ and ‘zoning out’ as competing characterizations of EGM immersion. We examined experienced gamblers’ natural gaze behaviour while using a genuine EGM. The ratio of dwell time on the game’s credit window over dwell time on the reels was positively related to immersion. This finding corroborated, and was predicated upon, the same relationship observed in the convenience-sampled pilot study. Notably the replicated effect was somewhat smaller, though still statistically significant. Thus, immersed participants were relatively more concerned with financial ‘performance’ related information and less concerned with the game's appealing animations. We tested relationships between immersion and the ratio of fixations per minute on the credit window over the reels, and with problem gambling severity, but we did not find support for these additional hypotheses.

In exploratory analyses, the total number of saccades explained 15% of the variation in immersion scores, but was not associated with saccade amplitude. Thus, immersed gamblers differed in the amount they looked back and forth, but this did not depend on the exact pattern in which saccades occurred. Since less than 1% of dwell time was spent off-screen, we argue that immersed participants were more thorough in their inspection of the game screen. GRCS subscales indicated higher levels of illusory and predictive control in more-immersed participants. Thus, belief in one's control over gambling outcomes may be elevated in gamblers who experience immersion.

These results strongly support a 'zoned in' interpretation of EGM immersion that entails persistent interest in task performance. In the 'zoned in' model, immersion is a potential motivator – but not the *sole* motivator – of continued EGM use among immersed individuals. We associated immersion with a focus on monetary outcomes, increased inspection of the game screen, and a stronger sense of control over gambling outcomes; all of which are hard to reconcile with a 'zoned out' or negative reinforcement-only model of EGM immersion.

At the same time, not every result supported the 'zoned in' model. Event-related analyses revealed significant interactions between immersion and fixating on the game's reels and win window. Although immersed gamblers were less likely to fixate on the reels during some outcomes, this was not coupled with a significant increase in fixations at the credit or win windows. Arguably, these interactions could be more consistent with a general disengagement from the game predicted by the ‘zoned out’ model. However, these exploratory analyses were not consistent across outcome types, and further study is needed to establish reliability.

Several limitations are of note. Our laboratory environment was quiet, minimally distracting, and our protocol required gamblers to use a specific bet strategy. Although we selected a popular strategy (maximum paylines, minimum credits; 42,43), it is likely not the preferred bet style for all gamblers. Both factors reduce ecological validity compared to gambling in real venues. We declined to test high-risk problem gamblers, as participant payment ensured the gambling session would have a positive expected value, producing an unrealistically-favourable gambling experience. As we sampled exclusively from craigslist (Gioia, Sobell, Sobell, & Agrawal, 2016), and excluded high-risk problem gamblers, our results may not generalize to eye movements or immersion for clinical populations (Thomas, Sullivan, & Allen, 2008).

Our instruments were subject to important limitations as well. The psychometric properties of our immersion questionnaire are not well understood. The scale has not been rigorously validated for internal or external validity. Additionally, we selected a small number of eye movement metrics we believed would be informative. Measures such as pupillometry may alter our interpretation of EGM immersion.

Irrespective of immersion, our event-related analyses found interesting eye movement patterns across different phases of EGM spins. The likelihood of fixating on the win window before starting the next spin (i.e. during the spin initiation latency) increased after wins, bonuses and losses-disguised-as-wins, but not losses (Figure 10). Fixations on the credit window, however, were more likely after wins and bonuses, but less likely after losses and losses-disguised-as-wins. Attention to the win window could contribute to the often-reported confusion between losses-disguised-as-wins and true wins (Graydon, Dixon, Stange, & Fugelsang, 2018). Notably, the relative infrequency of bonus feature outcomes prevented us from bootstrapping their confidence intervals, and may have also impacted the reliability of their odds ratios. Replication is especially important for these analyses.

These trends raise useful implications for responsible gambling messaging. On-screen pop-ups appear to be somewhat effective in reducing time on device (Blaszczynski, Gainsbury, & Karlov, 2014; S. Gainsbury et al., 2015; Kim, Wohl, Stewart, Sztainert, & Gainsbury, 2014; Tabri, Hollingshead, & Wohl, 2019). Stewart and Wohl (M. J. Stewart & Wohl, 2012) found that pop-up reminder messages improved spend-limit adherence. In real-world settings, however, the effect may be smaller (Auer, Malischnig, & Griffiths, 2014), and may diminish with repeated exposure (Hing, 2003; Moodie & Reith, 2009). Careful tailoring of message presentation could enhance these tools' effectiveness: eye tracking results could be used to optimise on-screen message delivery both spatially (by AOI) and temporally (by phase or outcome) to coincide with gamblers' attention. We found that fixations often increased at the credit and win windows in the spin initiation latency following wins, losses-disguised-as-wins, and bonuses. Messages presented there and then have the potential to garner greater engagement and resist habituation.

More broadly, these results speak to the conceptualization of immersion as a robust correlate of problem gambling. For problem gamblers, their families, clinicians, and venue staff, approaching gambling immersion as just one harmful example on a spectrum of immersive activities (including hobbies, playing sports, etc.), may be more productive for research and less stigmatizing than an approach that treats immersion as uniquely mollifying and solely achievable through gambling. To that end, we recommend adopting the terms 'immersion' or 'flow' (Dixon et al., 2018) to describe the experience.

Chapter 5: Subjective Immersion in Gambling Affects Pupillary and Behavioural Responses to Real Slot Machine Outcomes

5.1 Introduction

Gambling has been widely portrayed as exciting, and excitement has been argued to play a role in the onset of problem gambling (Binde, 2007; Boyd, 1982; McMullan & Miller, 2008, 2010). Many research studies have examined the effects of gambling activities on markers of the sympathetic nervous system. Several studies have reported significant increases in heart rate while gambling on electronic gaming machines (EGMs, including modern slot machines; Coventry & Constable, 1999; Coventry & Hudson, 2001; Griffiths, 1993; Ladouceur, Sevigny, Blaszczynski, O'Connor, & Lavoie, 2003), blackjack (Anderson & Brown, 1984; Meyer et al., 2000), and horse-racing (Coventry & Norman, 1997). Further, the size of wins in two simulated EGM tasks was correlated with increased skin conductance level (Dixon et al., 2013; Lole & Gonsalvez, 2017). Lole and Gonsalvez (2017) found significantly elevated skin conductance levels following large wins on a simulated EGM task, but no elevation for small wins. The effect of large wins was absent among participants who were problem gamblers, suggesting that problem gambling is associated with a physiological hyposensitivity to wins (though this result has not been consistently replicated; see Diskin & Hodgins, 2003; Dixon et al., 2013). In sum, evidence from heart rate and skin conductance studies generally supports the notion that gambling elicits sympathetic arousal.

The interpretation of these experiments is complicated by inherent limitations of heart rate and skin conductance measures. Heart rate signals are under the dual influence of both the sympathetic and parasympathetic nervous systems (Berntson, Cacioppo, & Quigley, 1993; Murch & Clark, 2019b). For skin conductance, the slow time-course of the response constrains event-related analyses on modern EGMs where the interval between successive bets can be less than 5 seconds (Chu et al., 2018; Murch et al., 2017). In order to assess the role of the sympathetic nervous system in gambling, alternative markers are required with improved temporal resolution and clarity regarding the contributions of the sympathetic and parasympathetic nervous systems.

Pupillometry – the investigation of the size of the eye's pupil and its reactivity to external or internal events – is potentially suitable to examining autonomic arousal associated with real-world gambling activities. The pupil dilator muscle reacts within 200-2,500 milliseconds of stimulus onset (Lemercier et al., 2015). Rapid pupil dilation recorded in consistently-lit environments putatively indicates noradrenergic signaling via the sympathetic nervous system (Bradshaw, 1967; Einhäuser, 2017; Hess, 1965; Joshi, Li, Kalwani, & Gold, 2016; Murphy, O'Connell, O'Sullivan, Robertson, & Balsters, 2014), although dopamine transmission may have a modulatory role (Muhammed et al., 2016). The magnitude of pupillary responses is positively related to stimulus intensity (Janisse, 2006), and inversely related to stimulus probability (Friedman, Hakerem, Sutton, & Fleiss, 1973; Qiyuan, Richer, Wagoner, & Beatty, 1985). Pupil size is also related to basic properties of stimuli like luminance via the parasympathetically-modulated pupil light reflex (Cacioppo et al., 2007; Einhäuser, 2017). Importantly, sympathetic and parasympathetic influences on pupil size appear to interact such that putatively sympathetic responses may be greater under different light conditions (Steinhauer, Siegle, Condray, & Pless, 2004).

Within a decision-making framework, pupil dilation is also associated with multiple components including choice, uncertainty, anticipation, and reward. Pupil diameter is positively related to preference and perceived value in forced-choice paradigms (Cavanagh, Wiecki, Kocahr, & Frank, 2013; Laeng, Suegami, & Aminihajibashi, 2016; Simpson & Hale, 1969; Strauch, Greiter, & Huckauf, 2018). The effect has been specifically linked to participant choice, and not the motor component of choice selection (Einhäuser, Koch, & Carter, 2010). Further, outcome uncertainty elicits larger pupil dilations in the interval between choice and feedback (Colizoli, de Gee, Urai, & Donner, 2018; Urai, Braun, & Donner, 2017). A pupillometry experiment using the Iowa Gambling Task showed effects of both reward and uncertainty: significant pupil dilation was observed following positive reinforcement, and the effect was significantly greater when the card drawn came from a deck that paid larger rewards less often (Lavín, San Martín, & Rosales Jubal, 2014). Concordant results were reported for a two-choice lottery task where reward magnitude and infrequency were both significant predictors of pupil dilation (Cherkasova et al., 2018). In that study, pupil dilation was greater when rewards were paired with audiovisual cues, and when the prior outcome had been a win. In summary, pupillary responses appear to be sensitive to many aspects of decision-making that are involved in gambling behaviour, but pupillometry has not been reported during real EGM gambling.

Behavioural markers are also sensitive to reward value in gambling and risk-taking. Once an EGM's reels have stopped spinning and any audiovisual feedback has completed, the time taken by the gambler to initiate the next spin (hereafter, "spin initiation latency") tends to be longer following wins than losses (Chu et al., 2018; Dixon, Graydon, et al., 2014). When the average spin initiation latency is longer for reinforced spins than it is for non-reinforced spins, this is termed a post-reinforcement pause (see Delfabbro & Winefield, 1999; Dixon et al., 2014, 2013). The duration of spin initiation latencies correlates positively with the size of wins (Delfabbro & Winefield, 1999), and losses can have the opposite effect of shortening spin initiation latencies, when compared to net-neutral outcomes (Verbruggen, Chambers, Lawrence, & McLaren, 2017). Like pupillary responses, post-reinforcement pauses in gambling tasks may thus reflect the perceived value of different outcomes.

In the present study, we analyzed data collected from a sample of experienced EGM gamblers who played a genuine EGM while wearing eye tracking glasses. We extracted pupillary responses following each spin outcome. We examined whether winning outcomes produce greater pupil diameter changes than losing outcomes. We explored two additional positive outcome types typically found in modern EGMs: losses-disguised-as-wins (Dixon et al., 2010; Sharman, Aitken, & Clark, 2015) and free-spin bonus features (Livingstone & Woolley, 2008; Lole & Gonsalvez, 2017; L. F. Taylor, Macaskill, & Hunt, 2017). Losses-disguised-as-wins occur when the amount won is less than the amount bet on that spin. Regardless of the net loss of credits, losses-disguised-as-wins produce celebratory audiovisuals that cause these outcomes to be confused with actual wins (Barton et al., 2017).

Bonus features are mini-games within an EGM, and the most common variant is the ‘free spin’ bonus, which provides some number of free plays and proceeds without user input. Bonus features are rarer than standard winning outcomes and are often signaled by distinct, salient audiovisual cues (Dixon, Templeton, et al., 2015). However, relatively few studies have directly examined EGM bonus features. In one study, the introduction of a bonus feature to a simulated EGM task increased preference for that game in a sample of undergraduate participants, regardless of whether the bonus spins were free (L. F. Taylor et al., 2017). This suggests that the unique audiovisual aspects of bonus features may provide something of value to the gambling experience. Like wins, free spin bonus features may produce physiological arousal. In another study, increases in heart rate were associated with experiencing free spin bonus features among a sample of experienced EGM gamblers using a genuine EGM (Moodie & Finnigan, 2005).

We examined the interactions between these outcomes and gamblers' immersion state while gambling. *Immersion* refers to a subjective state of extreme attention towards the game that recent work identified as an important motive in many EGM gamblers (Dixon, Gutierrez, Stange, et al., 2019; Dixon et al., 2018; Murch & Clark, 2019b; Oakes et al., 2018; Schüll, 2012). An influential public health model of gambling argues that disordered gambling arises from the interaction between trait-level (personal) factors and game-level factors (Korn & Shaffer, 1999). Recognizing that some individuals may be prone to experiencing immersion while gambling, we tested whether responses to game-level effects were associated with self-reported immersion states.

We hypothesized that positively-reinforced outcomes (wins, losses-disguised-as-wins, and bonus features) would be associated with significantly greater pupillary responses and post-reinforcement pauses, relative to losing outcomes. We accounted for additional game-level variance by also modelling the number of spins played, and the number of credits held prior to a given outcome. After examining the effects of EGM outcomes and other game-level factors, we elaborated the models to test the hypothesis that game-level effects may significantly interact with self-reported immersion states during the session.

5.2 Methods

This paper reports analyses of pupillary and behavioural data from an experiment using eye tracking to investigate EGM immersion (Murch, Limbrick-Oldfield, et al., 2020). Some methods have been described in Chapter 4, but are provided here for the reader's convenience.

5.2.1 Participants

We tested 53 individuals who reported playing EGMs in the past year (32 men and 21 women; mean age = 33.53, SD = 12.30). Participants were recruited through craigslist.ca advertisements seeking experienced EGM gamblers. Participants had to be at least 19 years old and had played an EGM in the past 12 months, but could not be high-risk problem gamblers (i.e. all scored < 8 on the problem gambling severity index; Ferris & Wynne, 2001). The latter criteria was adopted for ethical reasons: since participants received some endowment funds to play a real EGM, this task represents a unique gambling situation in that it employs a positive expected value. We wanted to avoid providing an unduly positive gambling experience to individuals who previously reported severely adverse reactions to gambling. They had no history of neuropsychiatric or ophthalmic disease, or psychotropic medication use, and had no recent or severe traumatic brain injuries. Participants had normal or corrected visual acuity with prescription strength from -4 to +4 diopters.

Participants were paid $20 CAD for their participation, and up to $20 extra for any profit they earned in the EGM task. All experimental protocols were approved by UBC's Behavioural Research Ethics Board.

5.2.2 Apparatus

Participants were asked to gamble using an endowment of $40 cash on a genuine EGM ("Buffalo Spirit," Scientific Games Co., Las Vegas, NV) for 20 minutes, or until they ran out of credit. Bets were constrained to the popular 'maxi-min' strategy (Livingstone & Woolley, 2008; Templeton et al., 2015), wagering 1 credit on each of 40 paylines ($0.40 per spin) to ensure frequent reinforcement. The game was configured to hold 11% (i.e. at infinite spins, the game keeps $0.11 from every dollar wagered).

Participants initiated each spin (akin to a psychological experiment's 'trial') by pressing the spin button on the right-hand side of the fascia. The reels spun for approximately 4-6 seconds (Chu et al., 2018) and stopped to reveal one of four possible outcomes: a loss, a win, a loss-disguised-as-a-win, or a bonus round. Losses have no positively-reinforcing payouts or audiovisuals, and are the most common outcome. Wins and losses-disguised-as-wins involve both reinforcing payouts and audiovisual feedback, but on losses-disguised-as-wins, the amount won is less than the amount wagered (Dixon et al., 2010; Graydon, Dixon, Harrigan, Fugelsang, & Jarick, 2017). During audiovisual feedback for wins and losses-disguised-as-wins, the value displayed in the device's credit and win windows incremented slowly, counting up to the new credit balance and overall win size, respectively. Winnings accrued during a bonus feature were transferred to the participant's credit balance only after the last bonus spin had ended. The true value of a given win, loss-disguised-as-a-win, or bonus feature was therefore only known to participants at the end of any outcome-related audiovisual feedback.

The free spin bonus feature was signaled by the sequential appearance of three large, matching symbols anywhere on screen, triggering 15 or more free spins that began immediately and continued automatically (i.e. without the player being required to press the spin button). The free spin bonuses had a unique music track for the duration of the feature. Because of their continuity and lack of participant intervention, we treated the multiple spins within a bonus feature as a single entity. Following each spin, the payout and audiovisual feedback played for a duration that was proportionate to the size of the win. Afterward, the game became still, and waited for the participant to initiate the next spin. We defined this epoch as the spin initiation latency.

During the EGM gambling session, participants wore a pair of mobile eye tracking glasses that provided real-time, natural gaze behaviour from both eyes at a rate of 60 Hz (SMI, Teltow, Germany). Eye position data were calibrated using three corner symbols on the game screen, and recorded to a Samsung Galaxy Note 4 affixed to the back of the participant's seat. Participants were able to sit at a comfortable distance from the game, and their heads did not require stabilization.

5.2.3 Questionnaires

After the EGM task, participants completed an immersion questionnaire composed of the 5-item modified Dissociation Questionnaire (e.g. "I felt like I was in a trance while playing the slot machine," "I lost track of time while playing the slot machine"; Diskin & Hodgins, 1999; Jacobs, 1988) and the 2-item Flow subscale of the Game Experience Questionnaire (e.g. "I felt completely absorbed"; IJsselsteijn, de Kort, & Poels, 2013; Poels & Kort, 2007). Responses were given on a 5-point Likert scale ranging from “very slightly or not at all (0),” to “Extremely (4).” Questionnaire scores were averaged for each participant to yield a value from 0-4.

5.2.4 Data Analysis

5.2.4.1 Pre-processing

Data were pre-processed using SMI’s proprietary analysis software (BeGaze 3.7). A binocular average pupil diameter in millimetres (mm) was extracted at 60 Hz for the duration of the EGM session. To link the pupil data with EGM outcomes, we derived a time series of game events. Inside the EGM casing, we doubled the video signal sent to the game screen (using an HDMI splitter; OREI, Skokie, IL) and passed a duplicate signal (using AV.IO Video Grabber; Epiphan, Palo Alto, CA) to a video capture computer (running Debut 3.01; NCH, Greenwood Village, CO). Using an image recognition program developed in Python 2.7 using OpenCV (Intel, Santa Clara, CA), the video files were processed to create an output file that included the ‘trial by trial’ spin outcomes, the start and end times of each spin and audiovisual feedback phase, and the credits held prior to each spin (hereafter “prior credits”).

5.2.4.2 Pupillometry

For each spin outcome, three epochs were defined (see Figure 11): 1) a baseline epoch was calculated as the mean in the last 200 ms of the reel spin, 2) an audiovisual feedback epoch from 200 ms to 2,500 ms (Lemercier et al., 2015) after the reels stopped (T1; this epoch captures the response to the sensory feedback), and 3) an epoch between 200 ms to 2,500 ms after the offset of the audiovisual feedback (T2; the epoch captures the response to the final amount of the outcomes). We were interested in both the start (T1) and end (T2) of audiovisual feedback because T1 indexed the first instance when gamblers became aware that reinforcement would be delivered, and T2 indexed their response to finding out the actual monetary value of the reinforcement.

There are three points to note with these epoch definitions. First, the many audiovisual differences between different outcome types presents a challenge for selecting an appropriate pre-trial baseline period. This is particularly the case with free spin bonus features, which are triggered by a distinct, sequential revealing of three large, salient symbols as the spinning reels come to a stop. It is possible that pupillary responses may pick up on some of these baseline differences. We considered using an earlier baseline (for example, the first 200ms of the trial preceding a given outcome) as an alternative approach. However, this approach would increase the likelihood of confounding difference scores from different trials because the baseline measure from one trial may inadvertently pick up on outcome-related signals from the previous trial. It would also impair the comparability of the baseline and trial data by introducing a variable latency between these measurements that would be systematically longer in some outcomes. Second, due to the short duration (< 2,500 ms) of audiovisual feedback in some EGM outcomes, T1 and T2 for a given trial may be unavoidably overlapped by some amount, and this may disproportionately affect some outcomes (e.g. losses-disguised-as-wins). Third, the loss-related response is only available at T1 because no audiovisual feedback is delivered.

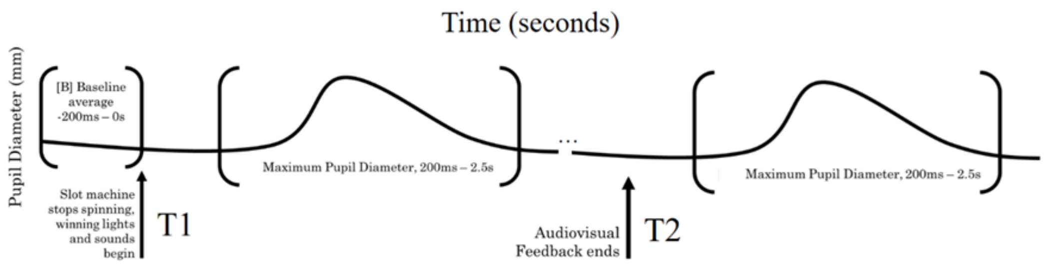


Figure 11. Recording epochs for pupillary responses

We calculated the peak dilation values in epochs T1 and T2. Missing pupil diameter data due to blinks and saccades were estimated using linear interpolation. If more than 18% of samples were missing due to blinks or saccades in a given epoch, it was discarded, as per published recommendations (Lemercier et al., 2015). Pupillary responses were calculated for epochs T1 and T2 as the percentage change in pupil diameter from the baseline epoch. A small fraction of pupillary responses was unreasonably large, likely due to equipment error, so we excluded 43 outlying values that were more than three standard deviations from the mean response. In total, 5,934 peak values were included. The resulting distribution of data was normal.

A fixed-effects regression model was created to predict pupillary response magnitude (Allison, 2012; Chu et al., 2018; Tobias-Webb et al., 2017). In a naturalistic EGM task, some participants experience a profit during short periods of play, while most experience moderate-to-heavy losses. Fixed effects regression allows us to address these multi-level data (i.e. trials nested within subjects), while avoiding imputation for data missing not at random (Allison, 2012). To that end, participant number was included as a factor, and the model intercept was suppressed.

In building the model, we first sought to examine the effects of game-level factors. Trial number was included to examine changes in the magnitude of pupillary responses over the duration of the task. Prior credits (centered on 4000, the initial endowment amount) represented the number of credits held prior to each spin, and was included because positive outcomes may show greater effects as participants' remaining credit approaches zero. The outcome epochs were represented as seven dummy-coded variables: losses at T1 (the reference category), winning outcomes for T1 and T2, losses-disguised-as-wins for T1 and T2, and bonus feature outcomes for T1 and T2. After testing the game-level hypotheses, we tested whether game-level factors interacted with participants' self-reported immersion state during the task; an interaction term was added for each previously-significant factor. As a result of the nested data structure and fixed effects approach, it was not possible to test an overall effect of immersion across participants. As such, these interaction terms indicate the extent to which the effects of other factors (different outcomes, trial number, and prior credits) depend on the levels of immersion self-reported by the participants. Data were analyzed using R version 3.5.2 (Fox & Weisberg, 2011; R Core Team, 2018; Wei & Simko, 2017).

5.2.4.3 Post-reinforcement pauses

The spin initiation latencies were not normally distributed, as is common for latency data. Data were log-transformed and the subsequent distribution of scores appeared normal. In total, 9,347 spin initiation latencies were observed. A fixed effects regression model was created to predict the spin initiation latency for the three positively-reinforced outcome types relative to that of losses. As in the pupillometry model, we first examined game-level factors: trial number, prior credits, and outcome type. We fit three dummy-coded outcome types (wins, losses-disguised-as-wins, and bonus features). After testing the game-level hypotheses, we once again tested whether significant game-level factors interacted with participants' immersion levels.

The post-reinforcement pause effect was conceptually defined for each 'positive' outcome (wins, losses-disguised-as-wins, bonus features) as the spin initiation latency for that outcome type, minus the spin initiation latency for losses (the reference category). Although the associated analyses were conducted on spin initiation latencies, the post-reinforcement pause is in this case reflected by the regression model's coefficient estimates for wins, losses-disguised-as-wins and bonus features, which are represented as relative effects compared to the model's reference category, loss outcomes.

Diagnostic plots for both the pupillary response model and post-reinforcement pause model were inspected to assess linearity, leverage, and homoscedasticity for both models' residuals. Multicollinearity was assessed by calculating variance inflation factor (VIF), where variable tolerances (1/VIF) were all greater than .20 (A. Field, 2012).

5.3 Results

5.3.1 Descriptive Results

The median participant in this experiment was exposed to a large number of loss outcomes, a smaller number of wins and losses-disguised-as-wins, and very few (if any) free spin bonus features (Table 6). Fourteen participants did not experience a bonus feature, and there were 58 bonus features in total. The median duration of audiovisual feedback was about 75 seconds for bonus feature outcomes, and about 0.5 seconds for losses-disguised-as-wins. On a small subset of trials (32 losses, 10 wins, 9 losses-disguised-as-wins, and 2 free-spin bonus features), spin initiation latencies were zero seconds. These were likely due to the play button being pressed prior to the end of feedback, which can happen if the participant uses the device's stopper function (Chu et al., 2018). Spin initiation latencies equaling zero could also occur as a result of a participant choosing to repeatedly press the "Repeat Bet" button as fast as possible. Data on the occurrence of this kind of button pressing was not available in our apparatus. As a result of audiovisual feedback lasting less than 2,500 ms on many outcomes, T1 and T2 overlapped by some amount on 50.46% of wins, 98.32% of losses-disguised-as-wins, and 0% of bonus rounds. The median participant rated their EGM play session as "a little" immersive (1.14 out of 4, range = 0.14 – 2.86).

Outcome Type	Median Count (range)	Median Duration of Audiovisuals (range)	Median Duration of SIL (range)
Loss	140 (95 – 190)	–	1.17 s (0.00 – 45.77)
Win	17 (8 – 28)	2.36 s (0.05 – 72.73)	2.04 s (0.00 – 18.58)
LDW	18 (10 – 33)	0.47 s (0.18 – 15.60)	1.80 s (0.00 – 63.18)
Bonus	1 (0 – 4)	75.23 s (45.52 – 196.02)	2.57 s (0.00 – 13.18)

Table 6. Outcome Frequencies and Durations

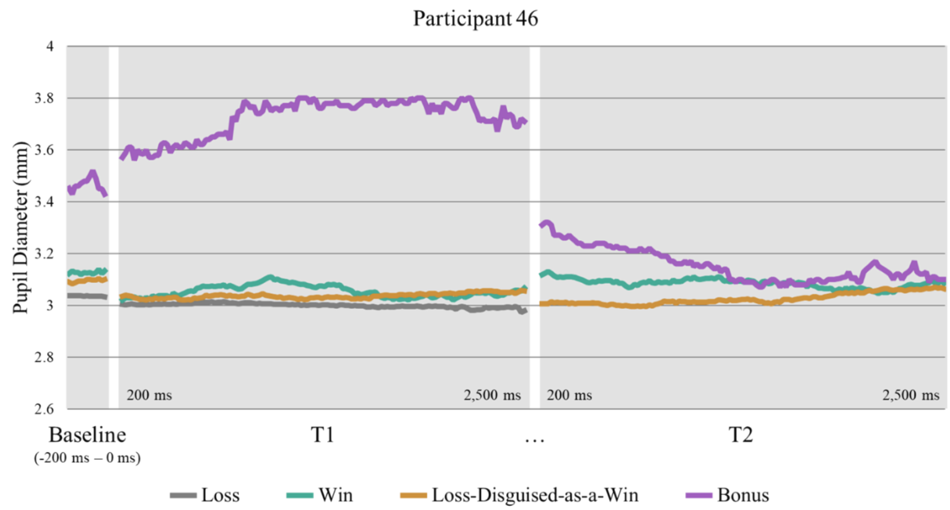
Note: Loss outcomes do not involve any audiovisual feedback. LDW = Loss-Disguised-as-a-Win. SIL = Spin Initiation Latency.

5.3.2 Pupillometry

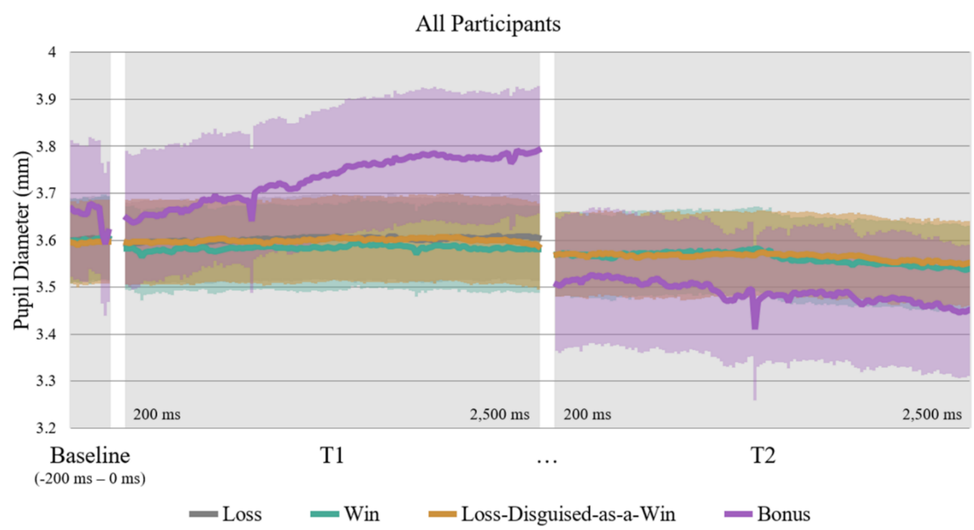
Our primary hypotheses were partially supported. Relative to loss trials, the free spin bonus features were associated with significantly greater increases in pupil diameter following the onset of audiovisual feedback (T1: B = 3.18, t(5830) = 3.83, p < .001, Table 7A, Figure 12). Wins (B = 0.09, t(5830) 0.43, p = .668) and losses-disguised-as-wins (B = -0.20, t(5830) = -0.96, p = .338) were not. Following the offset of audiovisual feedback (T2), we did not find evidence of reward-related pupil dilation. Instead, we saw a slight decrease in pupil diameter for wins relative to losses (B = -1.09, t(5830) = -4.99, p < .001), a larger decrease for bonus features (B = -3.24, t(5830) = -3.97, p < .001), and no significant difference for losses-disguised-as-wins (B = -0.25, t(5830) = -1.22, p = .223). Trial number was negatively related to pupillary response magnitude (B > -0.01, t(5830) = -3.32, p = .001, Table 7A), but participants' prior credits were not (B > -0.01, t(5830) = -1.71, p = .088).

A significant interaction effect was observed between immersion and bonus features at T2 (B = 4.31, t(5826) = 3.07, p = .002, Table 7B, Figure 12); pupil diameter in lower-immersion participants decreased more, relative to losses, than that of higher immersion participants. A significant interaction between immersion and trial number was observed ($B < 0.01$, $t(5826) = 2.00$, $p = .045$); low-immersion participants' pupillary responses to spin outcomes diminished more as the task went on. Model fit was significantly improved by the addition of the immersion interaction terms ($X^2(4) = 4.22$, $p = 0.002$, Table 7B). Overall, the interaction model accounted for 55% of the variance in task-related pupillary responses ($R^2_{adj} = .55$).

A)



B)



C)

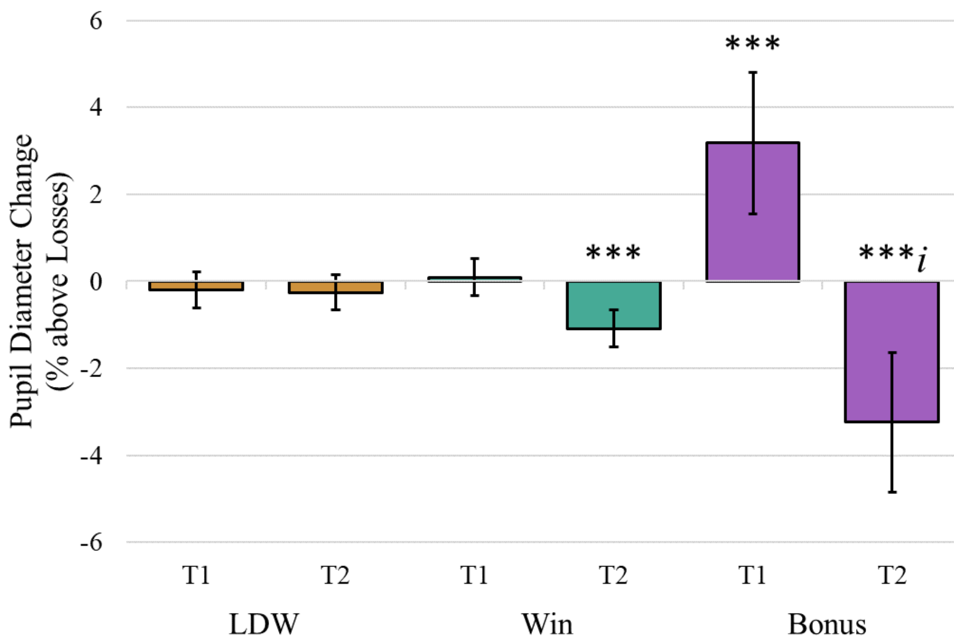


Figure 12. Change in pupil diameter by outcome type and immersion, for a representative single subject, and the full sample.

Note: **A)** Pupil diameter trace for a representative participant through Baseline, T1, and T2. Lines represent the different outcome types. Loss trials have no T2. **B)** Mean pupil diameter for all participants. Lines represent the mean of different outcome types. Shaded areas represents the standard error between subjects for that point in time. **C)** Predicted pupillary response to different slot machine outcomes, as percentage change from baseline minus the average response recorded for loss outcomes. Asterisks represent the effect of the outcome relative to the reference category, loss trials. Bars represent the 95% confidence interval. LDW = Loss-Disguised-as-a-Win, * $p < .05$, ** $p < .01$, *** $p < .001$, ***i*** = significant interaction between outcome type and self-reported immersion (see Table 7).

A)

Factor	*B*	95% CI	*t(5830)*	*p*	
Trial Number$_{(1)}$	>-0.01	[-0.01, >-0.01]	-3.32	.001	***
Prior Credits$_{(4,000)}$	>-0.01	[>-0.01, <0.01]	-1.71	.088	
Win T1$_{(Loss)}$	0.09	[-0.33, 0.52]	0.43	.668	
T2$_{(Loss)}$	-1.09	[-1.51, -0.66]	-4.99	<.001	***
LDW T1$_{(Loss)}$	-0.20	[-0.60, 0.21]	-0.96	.338	
T2$_{(Loss)}$	-0.25	[-0.66, 0.15]	-1.22	.223	
Bonus T1$_{(Loss)}$	3.18	[1.55, 4.80]	3.83	<.001	***
T2$_{(Loss)}$	-3.24	[-4.84, -1.64]	-3.97	<.001	***

B)

Factor	*B*	95% CI	*t(5826)*	*p*	
Trial Number$_{(1)}$ †	-0.01	[-0.01, >-0.01]	-3.53	<.001	***
Prior Credits$_{(4,000)}$ †	>-0.01	[>-0.01, <0.01]	-1.55	.120	
Win T1$_{(Loss)}$ †	0.09	[-0.33, 0.51]	0.42	.678	
T2$_{(Loss)}$ †	-0.47	[-1.32, 0.39]	-1.07	.283	
LDW T1$_{(Loss)}$ †	-0.21	[-0.61, 0.20]	-0.99	.321	
T2$_{(Loss)}$ †	-0.26	[-0.67, 0.15]	-1.26	.209	
Bonus T1$_{(Loss)}$ †	3.09	[0.09, 6.10]	2.02	.044	*
T2$_{(Loss)}$ †	-7.91	[-11.28, -4.53]	-4.59	<.001	***
Immersion x Trial	<0.01	[<0.01, 0.01]	2.00	.045	*
Immersion x Win T2	-0.60	[-1.32, 0.11]	-1.65	.098	
Immersion x Bonus T1	0.04	[-2.26, 2.35]	0.04	.971	
Immersion x Bonus T2	4.31	[1.56, 7.05]	3.07	.002	**

Table 7. Event-related change in pupil diameter as a percentage of baseline by trial number, outcome type, monetary factors and immersion.

Note: Full models have been included for main effects (A), and interaction effects (B). Coefficients represent percentage increase in pupil diameter per unit increase of the factor. Subscripted values represent the default value for each factor. Conditional effects (†) necessarily contribute to the interaction model, but are not used to test main effect hypotheses. LDW = Loss-Disguised-as-a-Win. * $p < .050$, ** $p < .010$, *** $p < .001$.

5.3.3 Post-Reinforcement Pauses

In line with a classic post-reinforcement pause effect, wins (B = 0.53, t(9289) = 34.46, p < .001, Table 8A, Figure 13), losses-disguised-as-wins (B = 0.41, t(9289) = 28.76, p < .001), and bonus features (B = 0.68, t(9289) = 11.82, p < .001), were each associated with significantly longer spin initiation latencies compared to losses. Spin initiation latencies decreased as trial number increased, indicating that participants took shorter pauses toward the end of the gambling session (B > -0.01, t(9289) = -23.07, p < .001). Participants' spin initiation latencies were positively related to the credit they held prior to the spin (B < 0.01, t(9289) = 3.24, p = .001).

Significant immersion interaction effects were observed for wins (B = 0.05, t(9284) = 2.34, p = .020, Table 8B), losses-disguised-as-wins (B = 0.09, t(9284) = 4.00, p < .001), and bonus features (B = 0.26, t(9284) = 2.70, p = .007); post-reinforcement pauses were longer in participants who reported higher immersion. Prior credits also showed a significant positive interaction with immersion (B < 0.01, t(9284) = 2.43, p = .015). The fit of the game-level model was significantly improved by the addition of immersion interaction terms ($X^2(5) = 8.63$, p < .001, Table 8B). Overall, the player-product interaction model accounted for 57% of the variance in post-reinforcement pauses ($R^2_{adj} = .57$).

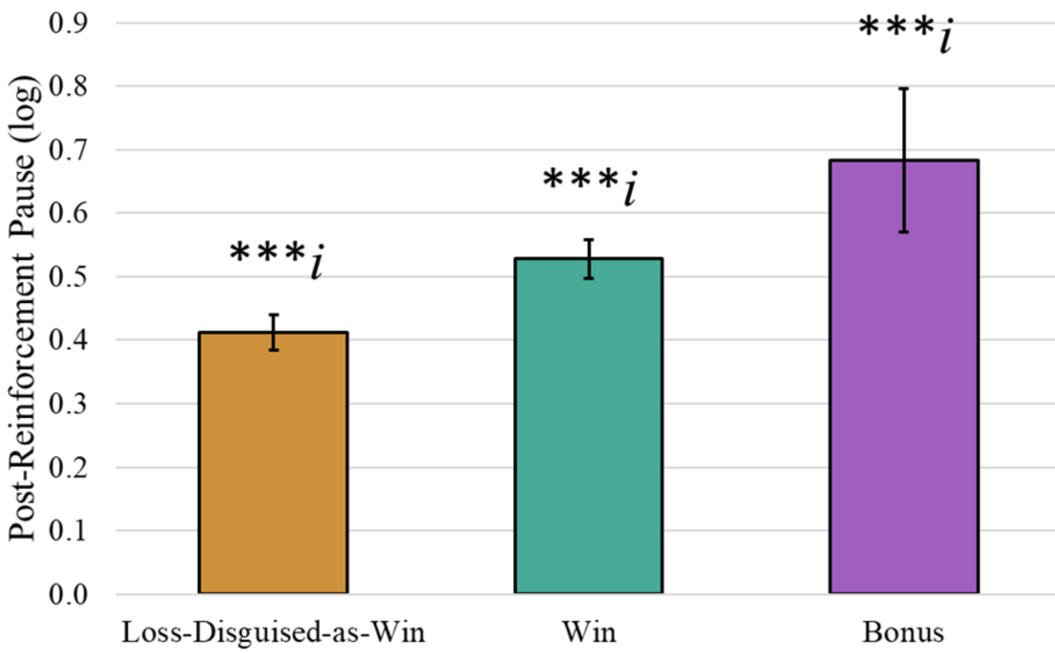


Figure 13. Post-Reinforcement Pause by outcome type and self-reported immersion.

Note: Bars represent the 95% confidence interval. Asterisks represent the effect of the outcome relative to the reference category, loss trials. * $p < .05$, ** $p < .01$, *** $p < .001$, ***i*** = significant interaction between outcome type and self-reported immersion (see Table 8).

A) Factor	B	95% CI	$t(9289)$	p	
Trial Number$_{(1)}$	>-0.01	[>-0.01, <0.01]	-23.07	<.001	***
Prior Credits$_{(4,000)}$	<0.01	[<0.01, <0.01]	3.24	.001	**
Win$_{(Loss)}$	0.53	[0.50, 0.56]	34.46	<.001	***
LDW$_{(Loss)}$	0.41	[0.38, 0.44]	28.76	<.001	***
Bonus$_{(Loss)}$	0.68	[0.57, 0.80]	11.82	<.001	***

B) Factor	B	95% CI	$t(9284)$	p	
Trial Number$_{(1)}$ †	>-0.01	[>-0.01, >-0.01]	-10.28	<.001	***
Prior Credits$_{(4,000)}$ †	>-0.01	[>-0.01, <0.01]	-0.82	.415	
Win$_{(Loss)}$ †	0.47	[0.41, 0.53]	15.25	<.001	***
LDW$_{(Loss)}$ †	0.31	[0.26, 0.37]	10.80	<.001	***
Bonus$_{(Loss)}$ †	0.39	[0.16, 0.63]	3.26	.001	**
Immersion x Trial Number	>-0.01	[>-0.01, <0.01]	-1.51	.132	
Immersion x Prior Credits	<0.01	[<0.01, <0.01]	2.43	.015	*
Immersion x Win	0.05	[0.01, 0.10]	2.34	.020	*
Immersion x LDW	0.09	[0.04, 0.13]	4.00	<.001	***
Immersion x Bonus	0.26	[0.07, 0.44]	2.70	.007	**

Table 8. Post-reinforcement pauses by trial number, outcome type, monetary factors and immersion.

Note: Full models have been included for main effects (A), and interaction effects (B). Analyses were performed on log-transformed spin initiation latencies. Coefficients represent log seconds increase in post-reinforcement pause per unit increase of the factor. Subscripted values represent the default value for each factor. Conditional effects (†) necessarily contribute to the interaction model, but are not used to test main effect hypotheses. LDW = Loss-Disguised-as-a-Win. * p < .05, ** p < .01, *** p < .001.

5.4 Discussion

We investigated potential behavioural and physiological markers of appetitive outcome processing among experienced gamblers in an authentic EGM task. We created regression models that included both game- and gambler-level factors, and accounted for over half of the variance in both pupillary responses and post-reinforcement pauses. We observed significant pupil dilation in response to receiving free spin bonus features, consistent with sympathetic nervous system activation. Pupil diameter increased by 3.18% more on bonus feature outcomes than it did on loss trials (Table 6A). An appetitive task involving natural rewards reported similar effects for participants consuming chocolate (Lemercier et al., 2015). We found no evidence for the hypothesis that pupil diameter was sensitive to reinforcement from wins and losses-disguised-as-wins. The pupillary response for these other reinforcing outcomes was generally flat (Figure 12B), and their associated confidence intervals considerably overlapped the pupillary responses observed for loss trials (Figure 12C). At the same time, we found significant post-reinforcement pause effects for all three reinforcing outcomes: wins, losses-disguised-as-wins, and bonus features. These effects were significantly amplified among high-immersion participants.

We observed null effects of wins and losses-disguised-as-wins (relative to losses) on pupil diameter at T1. One possible explanation is that the experienced gamblers in this sample were familiar with wins and losses-disguised-as-wins, and thus were habituated to these outcomes. It is further possible that modern EGMs are mostly not arousing; their appeal could be more dependent on large, infrequent jackpot wins, or on providing interesting or immersive gameplay features. This would explain why we only saw an effect of the rarer, more-salient bonus feature outcomes. A third potential explanation concerns the many extraneous audiovisual features of the EGM device. Incidental changes in screen brightness during wins and losses-disguised-as-wins could trigger compensatory pupil changes via the pupil light reflex, potentially swamping any arousal-related effects of these outcomes. This possibility is discussed further in the limitations section below.

Bonus features have existed in EGMs (and other EGMs) for many years, and are thought to be important events for experienced gamblers (Livingstone & Woolley, 2008; Lole & Gonsalvez, 2017; Moodie & Finnigan, 2005), but they have received little research attention. This may be due to the widespread use of simplified, computer-simulated gambling tasks in gambling research. We note that the symbols that trigger bonus rounds on ‘Buffalo Spirit’ are physically larger, and accompanied by a loud and unique auditory flourish. Thus, the unique effects of these bonus rounds on pupil size may be due to their relative salience and infrequency. At the same time, the infrequency of bonus rounds means that these events occurred in only a subset of sessions (and therefore participants). This is an unavoidable limitation to these results, and we caution readers that the analyses involving bonus features draw upon a very small number of observations.

For wins and bonus features, we observed significant decreases relative to losses in pupil diameter at the end of audiovisual feedback. These effects were not observed following the end of feedback for losses-disguised-as-wins, which lasted for a shorter duration. There are at least two possible explanations for this effect. One interpretation is that these are genuine changes in physiological arousal that reflect disengagement from the game. Since bonus features last much longer and require no active continuation of play, it is possible that participants’ interest in play begins to wane during long outcomes. This would explain why the offset of outcome feedback (T2) saw somewhat decreased pupil diameter following bonus features (Figure 12B). Another possibility is that the apparent T2 decreases arise from the selection of the baseline period. Bonus features are unique in being signaled by a sequential reveal with incrementing audiovisual feedback (see Dixon et al., 2015). By using the final 200ms of the reel spin, baseline activity may already be amplified by the bonus feature symbols, and thus the decrease subsequently observed at T2 may reflect physiological recovery. We note that based on this reasoning, the effect size for the T1 pupillary increase on bonus features may be underestimated.

From the interaction between immersion and bonus features at T2, it appears that immersion mitigated participants' disengagement from play during longer outcomes. This meshes well with our finding that immersion mitigated diminishing pupillary responses across the EGM task; trial number saw both a significant negative main effect and a significant positive interaction with immersion. Low-immersion participants appeared to become less-responsive over time, but high-immersion participants did not. Interestingly, we did not observe any positive effects of wins, losses-disguised-as-wins, or bonus features on pupil diameter at T2. These data suggest that finding out how much money one has just won on an EGM spin may not be physiologically arousing for experienced gamblers, lending further support to the argument that immersion, not excitement, is the prevailing attraction of EGM gambling (Schüll, 2012). However, the unavoidable overlapping of T1 and T2 for many wins and losses-disguised-as-wins diminished our ability to treat these epochs as distinct phases of EGM gambling. If positive effects at T2 were present, they may have been masked by overlapping effects in T1.

In tandem with pupillary responses, we examined the effects of different outcomes on post-reinforcement pauses. We found significant increases in spin initiation latencies for all positively-reinforced outcomes relative to loss trials. Thus, a post-reinforcement pause effect was present for wins and losses-disguised-as-wins, as reported previously (Delfabbro & Winefield, 1999; Dixon, Graydon, et al., 2014). This finding supports the argument that losses-disguised-as-wins are processed psychologically as true cases of positive reinforcement (Barton et al., 2017).

The post-reinforcement pause effect observed on free spin bonus rounds is a novel finding, to our knowledge, although unsurprising given the high salience of these events and known appeal to experienced gamblers (Livingstone & Woolley, 2008).

Post-reinforcement pause effects interacted significantly with immersion for all reinforced outcomes, showing that higher-immersion participants took longer pauses before seeking their next reward. These effects provide further support for our stance that immersion is associated with increased engagement with the EGM task (Murch et al., 2019), rather than a 'zoned out' state akin to clinical dissociation (Jacobs, 1986, 1988). Past accounts of immersion in EGM play have argued that modern, multi-line EGMs increase immersion by encouraging a smooth, habitual pattern of play (Dixon et al., 2018; Schüll, 2012). In one case, it was argued that jackpot wins may produce an aversive reaction because they disrupt the continuity of EGM gambling (Schüll, 2012). Our results do not support this prediction, since the post-reinforcement pause contributes to the overall variability in pace of play, and since we found that immersed gamblers took longer post-reinforcement pauses. In other words, immersion was associated with a more variable pace of play in this experiment. This result reinforces the argument that the actions underlying addictive behaviours can be sophisticated, and are certainly much more than a repetition of simple motor plans (Beeler, 2012; Berridge, 2007).

The spin initiation latencies also varied as a function of the participant's current level of profit or loss in the game ('prior credit'). This effect appeared to be attributable to participants' immersion levels, because the addition of the immersion interaction term to the model rendered the main effect of prior credits non-significant (Table 7B). The most sensible explanation for these results is that immersion appears to be associated with spin initiation latency (evidenced by significant immersion interactions across all outcome types; Table 7B), and gambling sessions in which a given participant incidentally experienced more frequent reinforcement (likely resulting in greater credit gains) appeared to be rated as more immersive.

Overall, we observed two distinct patterns of effects of EGM outcomes on our behavioural and physiological measures. The post-reinforcement pause effect appeared uniformly across wins, losses-disguised-as-wins and bonus features, while the outcome-related pupillary effect was only observed following bonus features. We believe that pupillometry, in this case, indexed the degree of surprise or excitement elicited by the bonus features, consistent with past results (Preuschoff, Hart, & Einhäuser, 2011). Post-reinforcement pauses, on the other hand, were sensitive to all positively-reinforced outcomes, and appeared to scale with the amount of reinforcement provided. Bonus features have the longest reinforcing audiovisuals and the longest estimated post-reinforcement pauses, and losses-disguised-as-wins have the shortest reinforcing audiovisuals and the shortest estimated post-reinforcement pauses (Figure 13). We would encourage gambling researchers to measure multiple modalities within future studies, as disparate effects such as these can reveal mechanisms underlying gambling behaviour and experience.

Beyond those noted in Chapter 4, a number of limitations should be noted for these analyses. First, since this was a naturalistic study, we could not control any perceptual or phenomenal differences in EGM events or areas of the game screen, and we did not correct for individual differences in pupillary foreshortening (T. R. Hayes & Petrov, 2016). Our results may be affected or driven by participants' reflexive responses to changes in screen luminance during different outcomes (Einhäuser, 2017). In particular, pupil traces associated with wins and loss-disguised-as-wins appeared remarkably flat, and suggest the possibility that any real effects of these outcomes were swamped by the many incidental perceptual differences between them. Second, since we used a genuine EGM in the experiment, we could not control the frequency of different outcomes. This led to a relative lack of free-spin bonus features, diminishing the reliability of the reported coefficient estimates. We were also unable to control the exact nature of the participants' experience during the baseline epoch for our pupillary response measure. On bonus features, audiovisual features occurred before and during the baseline pupil measurement. For this reason, we strongly encourage others to replicate these effects prior to building on them.

Third, although the pupillary response has an improved temporal resolution compared to the skin conductance response, one EGM event in our task (losses-disguised-as-wins) was still almost always shorter than the 2,500 ms response epoch defined for T1 and T2. As a result, T1 and T2 for losses-disguised-as-wins are largely indistinguishable. Further, pupil diameter is governed by both the sympathetic and parasympathetic nervous systems, and the complex interactions of these systems may not be easily separable (e.g. Steinhauer et al., 2004). While the relatively high temporal resolution of pupillary methods offers some promise of measuring autonomic responses to genuine EGM events, EGM pupillometry experiments would likely benefit from a more sophisticated accounting of the factors that could impact the pupil light reflex (e.g. changes in luminance, flickering lights, sounds, and EGM spin outcomes). Future researchers may find success in employing a pupil deconvolution analysis (e.g. Wierda, Van Rijn, Taatgen, & Martens, 2012). Alternatively, future studies may benefit from using pharmaceutical manipulations that target autonomic systems. Pupil dilator (sympathetic nervous system) responses to EGM outcomes, and pupil sphincter (parasympathetic nervous system) responses to EGM illumination, could be minimized with the administration of dapiprazole and tropicamide, respectively (e.g. Steinhauer et al., 2004).

Together these results suggest that reinforcement from EGMs is rewarding and, in the case of free-spin bonus rounds, able to trigger pupillary dilation. These results add to a growing body of work that examines EGM bonus features in relation to physiological states and individuals' risk of problem gambling. We believe that mobile eye tracking technology offers a valuable tool for exploring gamblers' reactions to gambling products and environments. At the same time, this experiment was highly exploratory, and the naturalistic pupillometry methods employed may have failed to capture potential effects of some outcomes. We strongly encourage pre-registered replication attempts to quantify pupil changes during EGM use.

Chapter 6: Conclusion

Across four experiments, I sought to characterize the behavioural and physiological correlates of immersion experiences during electronic gaming machine (EGM) use. The overarching goals of these experiments were to: 1) identify potential markers of immersion in EGM gambling beyond retrospective, self-reported states, and 2) achieve an improved understanding of the immersion phenomenon. To these ends, I hypothesized that: 1) immersion in EGM gambling produces measurable shifts in behaviour and physiological arousal, and 2) that EGM immersion is related to gamblers' behavioural, and physiological responses to specific EGM structural characteristics, specific regions of the EGM screen, and specific EGM outcomes. In the final chapter of this dissertation, I will assess whether my goals have been met, and the extent to which the evidence supports my hypotheses. I will outline the work that still needs to be done, presenting a number of future research directions that I believe will clarify and extend this work. I will reiterate a number of key strengths of the approach taken in these experiments. I will spend a significant portion of this chapter discussing key limitations of these experiments, and what may be done to minimize these problems in future research. Finally, I will discuss a number of short- and long-term directions for follow-up research.

6.1 Summary

The experiment described in Chapter 2 sought to examine the effects of modern, multi-line EGMs on self-reported immersion states, and whether multi-line EGMs or immersion were associated with parasympathetic nervous system activity. We found that immersion was significantly higher in multi-line bets when compared to smaller single-line bets, but not in bets where the overall stake was increased without increasing the number of lines played. This result both replicated and clarified a previous experiment by Dixon and colleagues (2014). Whereas past research had found higher rates of immersion in larger, multi-line betting scenarios, we showed that this effect was not due to simple increases in the overall size of the wager, but was indeed the result of multi-line gambling. We also replicated a physiological effect that we previously observed (Murch, Chu, & Clark, 2017), showing that cardiac Respiratory Sinus Arrhythmia (RSA) was significantly and uniformly lower during EGM use relative to resting baseline levels. This reinforced our previous conclusion that tonic parasympathetic nervous system activity may be relatively lower while gambling on an EGM, consistent with parasympathetic withdrawal. Interestingly, the rate of RSA decrease did not depend on multi-line betting strategies or individual immersion levels. We found significant increases in respiration rate during these same epochs. This suggested that observed decreases in RSA may be associated with increasing attentional load, as the relationship between RSA and attentional load appears to depend on respiration rate (Althaus et al., 1998). However, the lack of variation between different betting strategies suggested that this measure alone may not be sufficient to capture nuanced attentional effects associated with different EGM features or immersion levels.

Following the results of Chapter 2, we suspected that physiological effects of EGM immersion may be subtle, and may require large samples to detect in naturalistic gambling experiments. Chapter 3 focused on an additional cardiac measure recorded in Chapter 2, alongside two additional datasets. This experiment sought to examine the potential relationship between EGM immersion and sympathetic nervous system activation across the span of a gambling session. Whereas past research on arousal during gambling has often relied on heart rate (a measure that is impacted by both the sympathetic and parasympathetic nervous systems), we used cardiac pre-ejection period (PEP), an impedance cardiography-derived marker of sympathetic nervous system activity. We investigated whether EGM gambling was generally arousing, whether these effects changed over time, and whether arousal depended on individuals' immersion state. In a sample of more than 200 people, we found that EGMs did not produce significant changes in pre-ejection period overall. Along with our findings from Chapter 2, this result raises the possibility that past research on heart rate during gambling may not have been indicating sympathetic arousal associated with excitement, but rather parasympathetic withdrawal linked to increases in attentional load. To be clear, gambling does appear to impact sympathetic arousal in some cases: several experiments have shown increased skin conductance following winning EGM outcomes (Barton et al., 2017). However, the results of Chapters 2 and 3 call into question whether past research on gambling and heart rate has been measuring excitement, attention, or something else.

Chapter 3 also revealed that individuals who self-reported higher levels of immersion while gambling showed significantly greater EGM-related changes in PEP. Interestingly, this effect was only present during the first 5 minutes of the gambling session, indicating that individuals who found the session immersive tended to be those who experienced some kind of sympathetic response shortly after the onset of gambling. Thus, it may be the case that people who have a stronger physiological reaction to EGMs are more likely to experience immersion, and such responses may be associated with an elevated risk of experiencing gambling problems.

Chapters 2 and 3 emphasized the importance of understanding more about attention during immersed EGM use. In chapters 4 and 5, we pivoted away from cardiac measures of autonomic arousal to an eye tracking approach that allowed us to examine overt attentional processes and autonomic responses using a single, relatively unobtrusive apparatus. These latter chapters present results from a convenience-sampled pilot group, and a pre-registered follow-up sample of experienced EGM users from the community.

The analysis described in Chapter 4 sought to examine two competing models of EGM immersion using eye movement metrics. We wanted to understand what parts of the EGM screen gamblers look at, how that might depend on what the EGM is doing at a given moment, and how both of these things may vary with individuals' state of immersion. When the eye movement data were normalized to account for the relative size of each region of the EGM screen, it was clear that gamblers spend a disproportionate amount of time looking at the window displaying their remaining credit. Overall however, our sample of gamblers spent most of their time looking at the EGM's spinning reels, and were most likely to look at the reels when they were actively spinning. These findings, though likely unsurprising to many, were novel in the gambling field.

With respect to eye movement behaviour among gamblers who reported immersion in gambling, we found a pattern of results consistent with increased attention to the game (which we called "zoning in"), rather than a general state of relaxation or passivity ("zoning out"). Consistent with our pre-registered primary hypotheses, immersion was significantly associated with a visual bias toward the credit window, and away from the reels. Greater immersion was also associated with making a greater number of saccades. Since the vast majority of participants' fixations were recorded on the EGM screen, we interpreted this result as suggesting that immersed gamblers were more interested in inspecting the EGM screen. Participants in the study were more likely to look at the game's win window following losses-disguised-as-wins, implicating this EGM feature in the win overestimation effects that others have reported (Barton et al., 2017). High immersion participants were not as likely to show this trend, however, suggesting again that these individuals may have a greater awareness of what the game is doing.

Collectively, the results in Chapter 4 improved our understanding of EGM immersion, indicating that it is more like a flow state, or narrowed attention (Diskin & Hodgins, 1999; Dixon et al., 2018), and less like a state of dissociation in which winning becomes unimportant (Schüll, 2012). In terms of reinforcement, these results indicated that EGM immersion may involve motivations towards both positive reinforcement in the form of EGM winnings, and negative reinforcement in the form of escape from low mood or stress (‘zoning in’). They do not support the view that EGM immersion involves a motivation towards negative reinforcement by itself (‘zoning out’). Finally, these results demonstrated that mobile eye tracking technology can be used to examine nuanced behaviours associated with specific outcomes on real gambling devices.

The final experiment, reported in Chapter 5, sought to investigate physiological and behavioural responses to different EGM outcomes using pupillometry and the post-reinforcement pause (PRP). We found that all positively-reinforced outcomes produced significant PRPs, consistent with a perception of some reward by the gamblers. Each of these effects showed significant interactions with immersion, suggesting that this state amplified the level of perceived reward for all reinforcing spins. An increased importance placed on reward, or a disproportionately high perception of smaller rewards could explain why these gamblers were seen to disproportionately gravitate towards on-screen financial information, as shown in Chapter 4. Immersed gamblers interest in the outcomes of the EGM device also appeared more robust over time: we observed a significant decrement in the magnitude of pupillary responses as the task went on, but this effect was driven by lower-immersion participants. Participants who reported relatively higher immersion tended to show less habituation of pupillary responses to EGM outcomes.

We found significant pupil dilation effects associated with free spin bonus features, and this might indicate a significant sympathetic nervous system response to these outcomes. The low rate of occurrence of the bonus features, and our inability to control many extraneous perceptual factors in the naturalistic EGM paradigm suggests that this effect, and the null effects observed for other reinforcing outcomes, should be regarded as preliminary directions for future enquiry. Though we had been interested in investigating free spin bonus features among other EGM outcome types, it is clear that both refinement of these naturalistic methods, and attempts to replicate these effects, are warranted.

6.2 Hypothesis One

Immersion in gambling has been robustly linked to problem gambling, but past research has heavily relied on retrospective self-report measures. As such, the primary goal of these experiments was to identify behavioural and physiological markers of the immersion state for the purposes of predicting when immersion is occurring without having to ask gamblers after-the-fact. These experiments thus explored whether immersion was associated with distinct somatic effects using relatively unobtrusive behavioural and physiological measures while people gambled on real EGMs. My first overarching hypothesis – that immersion in EGM gambling produces measurable shifts in behaviour and physiological arousal – was supported. We found strong behavioural evidence to suggest that eye movement metrics and post-reinforcement pauses are linked to gamblers' immersion state during EGM gambling. Although we did not find evidence of an immersion association with a cardiac marker of parasympathetic nervous system activity, we did find evidence for a relationship between immersion and sympathetic nervous system activity during EGM use, as well as some outcome-related effects on pupil diameter.

These experiments could contribute to a measure of EGM immersion that looks beyond retrospective, self-reported states. In Section 6.4 below, I propose follow-up research that would use a multivariate model of behavioural and physiological factors to predict when immersion in EGM use is likely occurring on a moment-to-moment basis.

6.3 Hypothesis Two

The second goal of this dissertation was to provide an improved understanding of the phenomenon of gambling immersion. Specifically, we were interested in how individuals' experience of immersion in EGM use may be linked to their reactions to several features present in many modern EGMs. Our hope was that these efforts would help to further characterize the complex player-product interaction that we believe underlies EGM immersion. Hypothesis two – that EGM immersion would be related to gamblers' behavioural, and physiological responses to specific EGM structural characteristics, specific regions of the EGM screen, and specific EGM outcomes – was supported. In each of the experiments summarized in section 6.1, we associated immersion with distinct behavioural and physiological shifts during EGM use. In some cases, immersion was related to behavioural and physiological reactions to specific EGM features (e.g. multi-line bet strategies), areas of the EGM screen (e.g. the win window), and specific outcomes (e.g. reinforced outcomes). In the next section, I outline the implications of these findings for thinking about EGM immersion as a 'player-product interaction' (Korn & Shaffer, 1999), and provide a cognitive account of EGM immersion that speculates on why such a state might impair the diverse range of normal cognitive functions that have been qualitatively documented (Oakes et al., 2018; Schüll, 2012).

6.4 General Discussion

I believe that these studies have succeeded in identifying some candidate markers of immersion, though there is much work still to be done. Post-reinforcement pauses may provide some behavioural indication of individuals' relative immersion state while EGM gambling. The same could be said of eye movement metrics (e.g. saccade count) discussed in Chapter 4, as mobile eye tracking devices have recently reached new heights of affordability and ease of use. Pupillometry offers a potentially valuable marker of immersion, particularly across longer gambling sessions with many outcomes. However, in order to conduct pupillary analyses on real EGM gambling situations, a substantial amount of work needs to be done to characterize the perceptual effects of each outcome on each EGM device in order to control for confounding influences on the pupil light reflex. Cardiac PEP may be another candidate marker of immersion, particularly at the onset of gambling activities. However, it is relatively difficult to collect and analyze, requiring numerous gelled electrodes and sophisticated analysis software. PEP measures may be too onerous for some research and most real-world applications. At this point, it looks as though RSA is not a robust indicator of either EGM immersion or problem gambling (Kennedy et al., 2019; Murch et al., 2017; Murch & Clark, 2019b).

Immersion markers could be useful for public health efforts during real EGM use: interventions like on-screen pop-up messages could be linked to these markers to more-effectively target immersed individuals, who may be considered a high-risk group for gambling problems. Notably, one of these measures by itself is likely not sufficient to confidently identify at-risk individuals, and these are only a few of the many potential markers. Future research could test these and other potential markers with the specific intent of combining them in a multivariate risk model. Several other relevant considerations for physiological responses to real gambling activities are discussed in the section “Directions for Future Research” below.

From these experiments, it seems clear that EGM immersion is indeed one example of a ‘player-product interaction’ (Korn & Shaffer, 1999). Immersion effects were often greater when particular game features were interacted-with. These included multi-line gambling, the game’s credit window, and the outcome phase of EGM spins. The effects of other game features showed complex relationships with immersion. This included the interval between spins, from which we derived the post-reinforcement pause, and the device’s ‘win’ window.

These experiments can contribute to a more precise definition of EGM immersion. From these studies, and especially the hypotheses tested in Chapter 4, I believe that there is now clear evidence to suggest that EGM immersion in an active, motivated state rather than a more passive kind of ‘zoning out’. Combined with past research, it appears that EGM immersion is a motivated attentional state common among people who experience gambling problems (Chapter 4; Schluter & Hodgins, 2019). It may produce a narrowing of the scope of attention to predominantly the EGM screen (Diskin & Hodgins, 1999; Murch et al., 2017). It is reported retrospectively as a state of being ‘in a trance’, losing track of time, and forgetting about stimuli beyond the immediate gambling activity (Jacobs, 1988; Oakes et al., 2018; Schüll, 2012). Like Gambling Disorder (Blaszczynski & Nower, 2002), EGM immersion may be more common among individuals who experience significant physiological shifts when EGM gambling (Chapter 3; Jacobs 1986), as well as those who are experiencing stress, mood, or anxiety disorders, and those who gamble as a form of cognitive escape (Dixon et al., 2018, but see Chapter 4; McCormick et al., 2012).

The highly influential Pathways Model of Pathological Gambling (Blaszczynski & Nower, 2002) proposed that all cases of disordered gambling were associated with common conditioning experiences that result in a loss of cognitive control over gambling behaviour, but that individuals who gamble as a cognitive escape (perhaps including those who are seeking immersion in play) belonged to a distinct subset of gamblers who experience concomitant mood disturbances. In light of these and other contemporary results, it seems likely that the disturbances of normal attention described in EGM immersion lie on a continuum, much like those reported in 'normative' dissociation experiences (Butler, 2006). Immersion may be especially common in individuals who experience concomitant mood or anxiety disorders, but these conditions are not requisite. The experiments in this dissertation showed that immersion often occurs at high levels in individuals, irrespective of self-reported mood states and other factors.

A new model of the origins of EGM immersion could start with attention. Gambling and other potential behavioural addictions (e.g. video games, internet use) are somewhat unique among addictive products in that continued reward is predicated upon sustained attention. After consuming alcohol, one can spend at least a short time enjoying its rewarding effects. In order to keep experiencing reward associated with gambling, one needs sustain attention on the gambling activity. It is conceivable that the repeated conditioning of unpredictable rewards in gambling activities modifies the normal functioning of cue-related attention, biasing it towards gambling imagery (see Brevers et al., 2011; Mcgrath et al., 2018). Given the relative strength of gambling cues compared to natural rewards (Clark, 2014), it is conceivable that a sufficient amount of attention could be diverted to the locus of gambling imagery (e.g. an EGM) that other processes requiring regular cognitive maintenance begin to suffer. If reward learning results in such a great importance being placed on gambling imagery that other cognitive systems are less-attended, one could conceivably fail to attend to the passage of time, prospective memory functions, the necessity of bodily functions, perceiving the behaviours of passersby, or ruminations related to ongoing mood or anxiety conditions. All of these anecdotally-reported immersion effects (Oakes et al., 2018; Schüll, 2012) could result in an overall metacognitive assessment that one had been ‘in a trance’ for some period of time.

6.5 Research Strengths and Limitations

These experiments shared a number of common strengths. Chief among them is the fact that we endeavoured to examine gambling scenarios using only real EGMs that were available in BC gambling venues contemporaneously with our experiments. These efforts produced a number of additional methodological problems, mostly concerning our diminished capacity for stimulus control (i.e. the frequency and nature of different outcomes), but I believe that these problems were outweighed by the relative increase in ecological validity afforded by these genuine devices. For example, there is little prior research on the impact of EGM bonus features, because these complex, rare events are often not programmed into simplified simulations. In past reviews, we have noted that EGM research often relies on simplified, computer-simulated tasks that approximate EGM gambling (Murch & Clark, 2016). Although these simplified approaches may be acceptable or preferable in cases where strict stimulus control is required and high similarity to real gambling is not (as is the case in many behavioural economics tasks), immersion research is one case where I believe dissimilarity to past gambling experiences could seriously impair task-related immersive experiences. In these works, we have provided a number of useful examples for obtaining and analyzing the complex data associated with genuine EGMs, including image recognition algorithms for time series data extraction, and fixed effects regression for multi-level data with non-random missingness.

Another key strength of these works is the fact that we sought to investigate novel physiological methods. We have frequently noted the shortcomings of heart rate as a metric for isolating the origins of physiological responses to gambling activities (Murch et al., 2017; Murch & Clark, 2019b; Murch, Ferrari, McDonald, & Clark, 2020). By endeavoring to decompose electrocardiogram data into heart rate variability metrics like RSA, and by augmenting electrocardiograms with impedance cardiography to derive PEP, we have shown two ways that gambling studies can obtain more selective measures of autonomic function. It is our hope that these methods may be adopted more widely in future gambling research. In other existing datasets in which heart rate is estimated using photoplethysmography (i.e. pulse data), it may be feasible to estimate RSA (Schafer & Vagedes, 2013), and in doing so gain greater insight into the possible root causes of observed effects on heart rate. For example, if heart rate is seen to increase at the onset of gambling activities but RSA remains relatively stable, then one could make a stronger case that sympathetic arousal occurred as opposed to if they had only reported heart rate.

Another strength of these studies concerns our efforts to collect longer periods of EGM use, stratifying these sessions into multiple recording epochs. This necessarily made data collection more difficult and time-consuming, but provided clarity on the time-sensitive nature of some effects. For example, the PEP effect in Model 2 of Chapter 3 was specific to just the first few minutes of the gambling session. Had we only collected 5 minutes of data from each participant, we may have inadvertently implied that this effect was stable over time. Had we not decomposed the longer recording into 5-minute bins, our analysis may have lacked the sensitivity to detect this effect. Further, we have an increased level of confidence in more time-invariant effects like those of RSA in Chapter 2, because we employed a more-powerful mixed effects approach in analyzing multiple timepoints for each participant. Had we not examined the time course of these data, we could not have as-strongly suggested that this effect is stable over time. These effects were even more pronounced in Chapters 4, and 5, where we explicitly modelled time-sensitive factors (e.g. trial number) across the span of the whole task, so that effects could be accurately estimated at any point in time, rather than within a particular window or epoch.

A final strength of these experiments is our use of progressive data analysis tools. Several prominent gambling researchers recently called for improvements in the field's use of pre-registration, replication, and other Open Science practices (Wohl, Tabri, & Zelenski, 2019). I wholeheartedly agree with this assessment, and have worked the last few years towards publishing more transparent, more reproducible experiments. For Chapters 3, and 4, all data and analysis scripts have been publicly archived, so that anyone can replicate our analysis without having to inquire personally. Our openly transparent analyses improve the level of accountability for our findings and conclusions, and provide other gambling researchers with an example of how to achieve these ideals in future work. Chapter 4 was a pre-registered replication of convenience-sampled pilot data using a population of interest. I believe that this lends to the credibility of the findings reported with respect to our primary hypothesis.

These experiments also shared a number of key limitations. Chief among these limitations were the situational constraints we placed on participating gamblers. In order to gain greater control over the broader scenario of our EGM tasks, we required participants to complete the studies in our hybrid casino laboratory (S. H. Stewart et al., 2002). This gave us greater confidence that participants were engaging with the EGM device, rather than (for example) consuming alcohol or talking casually with someone else. However, our laboratory environment was visually distinct from a casino in a number of ways. The room was considerably smaller than a typical casino floor, covering only about 400 square feet. The walls were painted a uniform shade of white, and the carpet was a plain charcoal grey. This is a clear departure from most nearby gambling venues, which tend to have darker paint on the walls, and busily-patterned carpets. While we note in Chapter 4 that the vast majority of visual fixations during the gambling task were recorded on the EGM screen, we cannot rule out the possibilities that participants were 1) able to see these details using peripheral vision, and 2) already well-aware that this was not a typical gambling situation. Indeed, some ecological eye tracking research suggests contrary effects: gamblers in UK betting shops tend to look away from the devices quite often (Rogers et al., 2017). This could also be due to the relative seclusion afforded by our gambling scenario, compared to gambling in public venues.

In each of these studies, we further diminished the ecological validity of the gambling tasks by constraining the kinds of bets that participants were allowed to make. This gave us greater control over the length of gambling sessions (making it less likely that participants would quickly deplete their credit endowment), as well as the magnitude of winning outcomes (maintaining our ability to directly compare physiological responses to specific outcome types between participants). However, we cannot rule out the possibility that these constraints altered participants' perceptions of the gambling scenario, leading to different behaviours and physiological responses than would be typically expected.

In these experiments, high-risk problem gamblers – as indicated by the Problem Gambling Severity Index (Ferris & Wynne, 2001) – were not allowed to participate in EGM gambling, as we did not want to inadvertently provide an overly-positive gambling experience to individuals already experiencing clinically significant gambling-related harms. This necessarily restricts the population range to which these results apply. If a government or corporation were crafting its gambling policy based on some portion of these findings, they should seek to ascertain whether the effects also appear in people at risk of experiencing greater gambling harms. Follow-up research should look to replicate the observed effects in this vulnerable population, but should endeavour to do so with the appropriate safeguards in place. One viable option involves using large-scale field data from EGMs in gambling venues or online gambling platforms (e.g. Auer et al., 2014). This method is especially useful if linked to gamblers' accounts or casino loyalty cards. In-venue EGM experiments could include, for example, employing participant samples that are entirely voluntary (i.e. unpaid), alongside highly-realistic EGM simulations with a set sequence of bet outcomes that ensures a losing experience overall. This would help to avoid providing high-risk problem gamblers with a believable EGM gambling scenario that has a positive expected value overall, reducing the chance that the experiment will imply some benefit to EGM gambling. A preferable approach may be to have clinicians on hand during data collection to provide professional advice and clinical debriefing to participants who feel that participating in the experiment had increased their urge to gamble. This could help to provide individualized guidance and support to at-risk individuals, even in cases where the urge to gamble is not derived from a financial motivation.

A further limitation of these works concerns the immersion and flow questionnaires employed. These instruments have not been rigorously validated, and there has not been a standard established to delineate qualitatively different experiences of immersion across the range of possible scores. As such, there is no accepted benchmark in either the Jacobs

Dissociation Questionnaire (1986) or the Game Experience Questionnaire's Flow subscale (Poels, de Kort, & IJsselsteijn, 2013), to indicate what typical levels of immersion look like. Further, these scales do not include and reverse-coded items or indicators of socially-desirable responding. As such, participants may indicate relatively higher scores on these instruments if they happen to believe that we are expecting to see numerically higher scores. Further, group mean levels of immersion are not inherently meaningful, because there is no accepted indicator of central tendency or variance in these scales. For the benefit of future EGM research, these scales should be expanded to include multiple questions that attempt to probe the various constructs apparent in the questionnaires' original items. This will help to determine if the latent factor underlying 'losing track of time' is the same as the one underling 'memory blackouts'. It will further help to ascertain whether the construct(s) measured by the Dissociation Questionnaire are the same as those measured by the GEQ Flow subscale. Cronbach's alpha values in Chapters 2 and 4 provide some evidence for intercorrelation between these items, but these values only apply to the seven current questions, and do not employ rigorous validation procedures.

6.6 Directions for Future Research

A number of short- and long-term follow-up experiments are indicated by the results of these studies. Most immediately, it is important to replicate several of the exploratory findings reported here. This is less the case with the correlation between immersion measures and problem gambling severity, which has been robustly observed in a number of different contexts already (Schluter & Hodgins, 2019), and more the case with particular behavioural or physiological immersion effects that were observed. In particular, replication is needed for effects that were observed in relation to the EGMs' free spin bonus features, which tended to occur rarely in our EGM tasks.

Prior to applying these findings, it will be important to examine potential mediators of the relationships between immersion and particular behaviours or physiological effects. Assuming that the correlations reported in these experiments are reliable, the application of these findings depends on the direction of the effects, and whether or not they are driven by other factors. For the sympathetic arousal effects reported in chapters 3 and 5, ascertaining the direction of the effect is particularly important, as it will dictate how the effects can be applied. If immersion produces sympathetic arousal, then research and intervention efforts could target the extent to which gambling activities produce immersion, measuring the state by proxy using sympathetic arousal. This would provide an opportunity to estimate immersion while avoiding subjective, interruptive self-report measures. If, instead, immersion is caused by physiological states, then this approach may not be appropriate.

It may also be the case that relationships between immersion and behaviours or physiological states are explained by outside factors. Clarifying the relationship – and in particular the differences – between immersion and positive affective states is an important avenue for future research. Positive affect states appear to be strongly correlated with EGM immersion states (Dixon, Gutierrez, Stange, et al., 2019; Murch et al., 2017), and happiness has been associated with shifts in adrenergic signaling, as well as significant changes in HRV, PEP, and skin conductance level (Kreibig, 2010). One could challenge the whole of EGM immersion research on these grounds, arguing that immersion is just something that incidentally happens when people experience increases in positive affect while gambling on an EGM. This line of thinking is consistent with Flow Theory, which often emphasizes the mood-enhancing effects of this sort of absorptive experience (Csikszentmihalyi, 2014). However, the relationship between immersion and problem gambling has been very consistent, while associations between positive affect and problem gambling have been mixed (Dixon et al., 2018; Murch et al., 2017). It is thus possible that immersion represents a missing link between the much broader enjoyment of EGMs and the development of problem gambling among a subset of users, as others have argued (Schüll, 2012). Research in this area is ongoing, and the results of these efforts will certainly impact retrospectives interpretation of this document.

Flow theory is not the only portion of the field that generally regards absorption in digital products to be a positive thing. Largely separate from the gambling field, video game researchers have been interested in immersion for decades (Cairns, Cox, & Imran Nordin, 2014), and often approach the topic through a much more positive lens (e.g. Cheng, Lin, She, & Kuo, 2017). It is sensible that these fields have remained largely separate, as gambling activities have only recently come to resemble video games as closely as they do now. There is an opportunity to meaningfully unite these fields, integrating research on immersive digital products more broadly. The video games field could provide a number of novel insights into the phenomenon of EGM immersion. First, scholars interested in gaming immersion have published self-report measures such as the 31-item Immersive Experience Questionnaire (Jennett et al., 2008). Some of these items may be relevant to gambling immersion (e.g. “I did not feel the urge at any point to stop playing and see what was going on around me.”), while others may not (e.g. “It was as if I could interact with the world of the game as if I was in the real world.”).

Second, scholars make a useful distinction between ‘diegetic’, and ‘situated’ levels of immersion; the former referring to the experience of being highly-attentive toward the activity, and the latter referring to a deeper state of dissociation from the real world into the world of the game (L. N. Taylor, 2002). Similar models of immersion in gaming have been outlined by Brown and Cairns (2004). The diegetic-situated classification system is both well-situated in the flow-vs-dissociation debate described in Chapters 1 and 4, and uniquely insightful in charting two different forms of immersion that may be more flow-like, or more dissociation-like. The fit of this model to gambling situations has not been examined, to my knowledge, though this effort seems both relevant and timely.

The experiments in this dissertation frequently sought to investigate the utility of relatively novel psychophysiological measures in examining immersion in real EGM gambling. We were not able to test every physiological measure or approach, and novel approaches to established measures continue to emerge. Future researchers may endeavor to renew the field's interest in skin conductance responses to EGM outcomes, as this measure is easy to collect, and a relatively clear indicator of sympathetic nervous system functioning. Some gambling research has examined this measure in simulated gambling tasks (Dixon et al., 2013; Lole & Gonsalvez, 2017; Lole et al., 2014), although past efforts to examine EGM immersion in real games were not successful due to the relatively low temporal resolution (4 – 6 seconds) of the skin conductance response (Chu et al., 2018; Murch et al., 2017). In real EGM devices, bets are often completed in less than 5 seconds, leading to significant confounding of the physiological traces associated with specific events. Emerging approaches involving machine-learning-assisted deconvolution may help to clear up this problem for both pupillary and skin conductance measures in future research (Zhang, Ali, Wang, Zhu, & Cesar, 2019).

The results of these studies also raise the interesting possibility that EGM immersion could be measured in real gambling venues by integrating behavioural and physiological measures into the normal workings of EGM devices. Introducing code to examine post-reinforcement pauses using EGM devices' button panels would be exceedingly easy, and would require no hardware modification. Introducing physiological measures requires significant hardware modification and increases in processing power, but this has not dissuaded gambling firms from investigating the possibility. There are already at least two patents for EGM devices with integrated eye tracking. The first aims to use eye tracking technology as a means of locating gamblers' eyes, so that a unique identifier can be applied to each gambler, even those who are not known to the gambling venue (US6783459B2, 2002). The second, held by International Game Technology, aims to record eye movements as a means providing input to EGM devices, increasing the seamlessness of the player-product interaction (US20190384385A1, 2018). The inventors of this patent argue that eye tracking will be used in support of the industry's overarching goal "to provide a more immersive and attractive gaming experience".

It is thus clear that some of the metrics and methods described in this dissertation may be appealing to EGM designers. In research on gambling product characteristics and the psychology of gambling problems and harms, individual findings may conceivably be used for better or for worse. That is to say, to reduce gambling harms, or to (directly or indirectly) increase the harmfulness of gambling products. The research in this thesis was undertaken with the ultimate intent of addressing Gambling Disorder and reducing gambling harms. Although the patents above show that the gambling industry was already interested in these topics, it is increasingly important that the research and policy communities work to proactively address Gambling Disorder and EGM harms.

To that end, these experiments present an opportunity to design and test EGM interventions with the specific intent of reducing immersion and problem gambling harm. One such example involves optimizing pop-up messages on EGM screens. The appearance of on-screen pop-ups appears to be somewhat effective in reducing time on device (Blaszczynski et al., 2014; Gainsbury et al., 2015; Kim et al., 2014; Tabri et al., 2019). Stewart and Wohl (M. J. Stewart & Wohl, 2012) found that a pop-up spend-limit reminder message improved adherence even among participants reporting dissociation. Yet the effect of pop-ups tends to be small in real-world settings (Auer et al., 2014), and it may shrink further with repeated message exposure (Hing, 2003; Moodie & Reith, 2009). Though past results are promising, careful tailoring of message presentation may enhance these tools effectiveness across multiple exposures. The eye tracking results in Chapter 4 could be used to tailor on-screen message delivery both spatially (by specific area on screen) and temporally (e.g. by timing the message to coincide with specific in-game events) to coordinate with expected attentional or physiological states. For example, these Chapter 4 results showed that participants shifted their gaze towards the win window during most payouts. A message presented at the win window during payout could garner greater engagement and resist habituation. Alternatively, a pop-up presented over the reels at the outset of a free spin bonus feature may benefit from both elevated visual attention, and sympathetic nervous system arousal. Following this and other research avenues will be necessary to counter the continuing sophistication of digital gambling devices.

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