Exploring Personality: The Impact of Impulsivity on Decision Making and Reward Processing

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on Decision Making and Reward Processing

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Abstract

Impulsivity is a common and multifaceted personality trait that is characterized by the presence of heightened reward sensitivity, novelty seeking, lack of premeditation, and behavioural and emotional inhibition deficits (Leshem, 2016a). These behaviours are often associated with substance abuse, gambling disorders, obesity, abnormal time perception, and other psychological and neurological conditions (Bari & Robbins, 2013; Berlin & Rolls, 2004). Reward processing deficits have also been well documented, with many researchers finding an association between impulsivity and the inclination towards smaller, immediate, rewards over larger, delayed rewards (Petry, 2001). Additionally, a larger reward positivity amplitude – an event-related potential component associated with rewards and expectancy – was found for the immediate rewards, relative to delayed rewards in high impulsivity individuals (Cherniawsky & Holroyd, 2013; B. Schmidt, Holroyd, Debener, & Hewig, 2017). The purpose of this thesis was to replicate and extend previous findings, by having participants complete two tasks: delayed gratification and time estimation. In the time estimation task, participants estimated the length of one second. The first task, a replication, assesses subject's preference for immediate rewards; moreover, the second task extended previous research and functioned as an additional way of assessing reward processing and examined participant's ability to estimate time. Abnormal time perception in impulsive individuals is thought to contribute to atypical delay gratification behaviour (Wittmann & Paulus, 2008). Electroencephalography (EEG) was recorded from participants during both tasks. Based on previous research on impulsivity (Cherniawsky & Holroyd, 2013; Coull, Cheng, & Meck, 2011; Holroyd & Krigolson, 2007; B. Schmidt et al., 2017), I predicted that impulsivity would affect performance on the time estimation task (which is novel in its use with impulsivity and EEG), and response times and reward positivity amplitudes on both tasks. Counter to my hypothesis, I found that response times and task performance were not affected by impulsivity levels. I also observed that the reward positivity was mediated by impulsivity in the delayed gratification task, but not in the time estimation tasks, suggesting that the tasks activate different neural pathways for reward processing. My results indicate that impulsivity can influence the amplitude of the reward positivity, but that different neural pathways are associated with distinct tasks. Further investigation into quantifiable measures of impulsivity and their effect on various reward processing tasks needs to be conducted.

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List of Abbreviations Used

ACC	anterior cingulate cortex
ANOVA	analysis of variance
BIS-11	Barratt Impulsiveness Scale, version 11
EEG	electroencephalography
ERP	event-related potential
fMRI	functional Magnetic Resonance Imaging
OFC	orbitofrontal cortex

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Chapter 1: Impulsivity

Impulsivity is a common personality trait, characterized by the desire for immediate gratification, lack of premeditation, risk-taking, and attentional and behavioural inhibition deficits (Leshem, 2016a). Individuals with heightened levels of impulsivity are affected throughout their lifespan and are more likely to struggle with behaviours related to alcohol and drug use, gambling, unhealthy eating, risky driving, high risk sexual behaviours, monetary debt, single parenthood, unemployment, and more (Adams & Moore, 2007; Bari & Robbins, 2013; Caspi, Wright, Moffitt, & Silva, 1998; Doumas, Miller, & Esp, 2017; Leshem, 2016a; Moffitt et al., 2011). The multidimensional construct of impulsivity is also associated with Attention Deficit Hyperactivity Disorder, Bipolar Disorder, Obsessive Compulsive Disorder, Schizophrenia, Parkinson's Disease, and personality disorders (Berlin & Rolls, 2004; Heerey, Robinson, McMahon, & Gold, 2007; Moeller et al., 2001; Reddy et al., 2014; Robbins & Dalley, 2017).

Impulsive behaviour is a typical aspect of adolescent neurodevelopment, with many teenagers counterintuitively preferring smaller immediate rewards, over larger future rewards (Leshem, 2016a). Intriguingly, this neurodevelopmental phase of augmented impulsivity is expected to last until the individual reaches their mid-twenties, at which time additional neural pruning, development, and myelination of prefrontal cortex has occurred (Leshem, 2016a). This timeframe is characterized by the presence of an underdeveloped frontal lobe, specifically the orbitofrontal and prefrontal cortex regions (Leshem, 2016b). In order for the prefrontal cortex to fully develop, grey matter volume must decrease, and white matter volume needs to increase (Leshem, 2016b). This functions to improve executive functioning by making neural transmission more efficient. Additionally, during this timeframe important connections are maturing and being strengthened between the prefrontal cortex and the limbic system, allowing for better emotional regulation (Balocchini, Chiamenti, & Lamborghini, 2013). Importantly, it is not known why these developmental stages go awry, but when they do it is thought to result in higher levels of impulsivity, worsened emotional regulation, and decision making abilities within adult populations (Muhlert & Lawrence, 2015).

1.1 Impact of Impulsivity on Behaviour

It is common knowledge that children struggle to regulate their emotions and desires, as is readily apparent when children have tantrums. As children age, and their brains continue to develop, they act less impulsively and the tantrums become less frequent. Despite this, adolescent delinquency is common (White et al., 1994). As part of a longitudinal study examining the development of antisocial behaviour, adolescent boys – ages ten and 12 to 13 – were assessed on their levels of impulsivity and delinquent behaviour; moreover, results indicate that impulsivity was related to delinquency in this cohort (White et al., 1994). In a separate birth cohort, lack of impulse control was correlated with delinquency in 18 year olds (Caspi et al., 1994). Using the same cohort, impulsivity was related to unemployment rates when the participants were 21 years old (Caspi et al., 1998); furthermore, when the participants were 32 years old, impulsivity was associated with worse health, criminal activities, greater financial problems, substance dependence, and a higher probability of single parenthood (Moffitt et al., 2011). Further examinations into impulsive behaviour in high school students found that drug use, binge drinking, and negative consequences associated with drinking also increased with levels of impulsivity (Doumas et al., 2017; Shedler & Block, 1990).

Impulsivity plays a large role in the behaviours exhibited by university students. In one study, university students – ages 18 to 25 years old – completed questionnaires assessing their debt, self-control, substance use, psychological health, physical health, and risky behaviours (Adams & Moore, 2007). The researchers found that credit card debt and low self-control (i.e. high impulsivity) was associated with drunk driving, drug use, depression, higher body mass index, risky sexual behaviour, and lower grades. Another study using participants from the same age group used interviews to assess the relationship between impulsivity and risk, and observed that impulsivity was associated with augmented risky behavioural tendencies: unhealthy and abusive alcohol use, and risky sexual experiences (Cooper, Agocha, & Sheldon, 2000). Additionally, impulsivity was associated with risky and angry driving behaviours in student populations (Dahlen, Martin, Ragan, & Kuhlman, 2005). Impulsivity is not only associated with risk, in terms of substance use, sex, and driving, but also with problem gambling (Johansson, Grant, Kim, Odlaug, & Götestam, 2009).

Given the aforementioned associations with impulsivity, researchers have developed programs to aid in the development of self-control. In their meta-analysis, Gagne & Nwadinobi (2018) divide these interventions into four categories: (1) curriculum-based, where children are taught self-control techniques by completing a program in the classroom setting; (2) training, where children practice effortful control skills and are later tested in the laboratory or at home; (3) mindfulness, where children practice mindfulness to reduce stress and learn types of cognitive behavioural therapy; and (4) games and physical activity, which utilizes games and physical activity to teach control. Depending on the type of program, it may have been developed to be used on neurotypical children, or those with developmental and psychological disorders; however, these interventions are typically done in preschool age children (Gagne & Nwadinobi, 2018). After some time had passed (i.e. six months to a few years, depending on the study), researchers followed-up with the intervention participants, and found that their subjects had higher test scores, better self-regulation and impulse control, and attention (Brotman et al., 2013; Graziano, Slavec, Hart, Garcia, & Pelham, 2014; Greenberg, Kusche, Cook, & Quamma, 1995; Razza, Bergen-Cico, & Raymond, 2015). An additional meta-analysis examining the long-term effects of these programs found that they were associated with diminished teen pregnancy, delinquency, missed work days, and school dropout rates (Heckman, 2006).

1.1.1 Quantifying Impulsivity

Impulsivity is a diverse personality characteristic that can be assessed in various distinct means. As such, many self-report questionnaires have been created in order to properly measure impulsivity, with each one examining slightly divergent aspects of the construct. The most widely used questionnaire, the Barratt Impulsiveness Scale (BIS-11), was developed by Barratt (1959), and is currently in its eleventh iteration. The BIS-11 is a 30 item questionnaire assessing attentional, motor, and non-planning impulsivity and is the most commonly utilized scale by researchers and clinicians (Stanford et al., 2009). The scale was established to focus on impulsivity, and the relationship between impulsive behaviour and psychomotor activity (Stanford et al., 2009). As a way to focus on impulsivity, the scale was designed to emphasize the difference between anxiety and impulsiveness, which Barratt believed to be orthogonal constructs (Barratt & Patton, 1983). At this time, clinicians lacked a way of clearly delineating anxiety and impulsivity; additionally, such a measure was needed as many of the available tests lacked construct validity and their results were uncorrelated (Stanford et al., 2009). In an attempt to remedy this, Barratt found and developed questions that measured impulsivity without being correlated to anxiety; furthermore, this resulted in a questionnaire composed of many every day questions examining if an individual gives thought to the consequences of their actions (Robbins & Dalley, 2017). Later iterations added and changed the constructs believed to compose impulsivity. In the tenth iteration, the three sub-traits examined were *cognitive impulsiveness* (i.e. quick decision-making), *motor impulsiveness* (i.e. acting without thinking), and non-*planning impulsiveness* (i.e. lack of forethought; Stanford et al., 2009). These sub-traits were consistently found in further research (Gerbing, Ahadi, & Patton, 1987; Parker, Michael Bagby, & Webster, 1993; Patton, Stanford, & Barratt, 1995). After difficulty identifying *cognitive impulsiveness*, the eleventh and final version of this scale replaces it with a sub-trait termed *attentional impulsiveness* (i.e. the inability to focus or concentrate; Patton et al., 1995).

Since its development, the BIS has shown a high degree of correlation between its results and neurophysiological measures of impulsivity (Stanford et al., 2009). Further validating the BIS, research can been conducted that correlates structural abnormalities in the prefrontal cortex with measures of dysfunction in executive control (Reid, Cyders, Moghaddam, & Fong, 2014). The BIS has also been used in many psychological disorders: attention deficit hyperactivity disorder, bipolar disorder, kleptomania, obsessive-compulsive disorder, schizophrenia, gambling addiction, substance abuse, etc (Patton et al., 2009).

1.2 Neural Basis of Impulsivity

What neural factors then account for the behavioural changes observed in highly impulsive individuals? One potential mechanism is dopamine, whose regulatory genes have been linked with and play a major role in impulsivity (Dalley, Everitt, & Robbins, 2011). Studies of rhesus monkeys have shown that being subjected to high levels of stress during adolescence was associated with lower levels of dopamine receptors (i.e. D2 and D3) in the striatum; moreover, lower dopamine receptor levels are associated with increased levels of drug self-administration (Morgan et al., 2002). Interestingly, drug users were also found to have fewer D2 and D3 receptors in the striatum, suggesting that lower levels of dopamine prior to drug exposure may increase the risk of future drug abuse (Dalley et al., 2011). This indicates that individuals who experienced high levels of stress during adolescence are more likely to exhibit impulsive behaviours during adulthood, but impulsivity is not a unitary construct.

Other research, centered on the hypothesis that impulsivity is the result of executive dysfunction, have investigated the role of higher order and associational regions of the cortex in highly impulsive individuals (Horn, Dolan, Elliott, Deakin, & Woodruff, 2003). Several fMRI studies have implicated the prefrontal cortex as an area responsible for executive function, and that abnormalities within this region are associated with disorders relating to impulsivity (Horn et al., 2003). Specifically, neural networks attributed to the ventral frontal lobe, medial prefrontal cortex, and the anterior cingulate gyrus, have been recurrently associated with top-down control tasks in several fMRI studies (Hariri et al., 2006; Knutson & Cooper, 2005; McClure, Laibson, Loewenstein, & Cohen, 2004). Behavioural studies have largely corroborated these findings and have found that impulsivity may in be a result of lack of inhibitory control, something that is readily observed in patients with frontotemporal dementia, schizophrenia, bipolar disorder, and patients with lesions within the medial prefrontal cortex (Reddy et al., 2014). The role of the medial prefrontal cortex has been associated with the planning and execution of context dependent behaviour, and the avoidance of inappropriate behaviour (Reddy et al., 2014). This lack of inhibitory control, as seen in many psychiatric disorders, strongly resembles the behavior observed in impulsive individuals (Reddy et al., 2014).

When learning tasks, individuals with damage in the ventromedial prefrontal cortex have shown an impairment in learning and are more likely to commit errors during the learning and to make premature responses prior to fully comprehending the task. Additionally, this becomes apparent in Go/No-Go tasks, where impulsive individuals are more likely to “go” during a “no-go” trial and show impaired cortical activation of the ventromedial prefrontal cortex compared to their control cohorts (Arce & Santisteban, 2006). FMRI studies have observed delayed or attenuated activation of these regions of the cortex in non-lesioned impulsive individuals, demonstrating that impulsive individuals have similar deficits in the recruitment of the prefrontal cortex during Go/No-Go tasks (Asahi, Okamoto, Okada, Yamawaki, & Yokota, 2004). Emotion-based impulsivity centers around irrational decision making by impulsive individuals or individuals in temporary impulsive trances, with the aid of alcohol and drugs (Cyders et al., 2014). As expected, individuals under the influence of alcohol, are often in extreme emotional states, and are more likely to behave impulsively without thinking about the consequences of their actions. Negative correlations have also been reported between the conducting of rash actions, and grey matter activation and volume within the dorsomedial prefrontal cortex (Muhlert & Lawrence, 2015).

1.2.1 Reward Processing.

Impulsivity not only influences response inhibition, but also how rewards are processed. Rewards can be monetary, food related, or experiential. Importantly, a reward’s subjective or perceived value can differ between individuals and even within an individual across time. Individual differences in reward processing can be attributed to anatomical and neurochemical differences between people (Dalley & Roiser, 2012; Dalley et al., 2011).

Similar to impulsivity, the neural basis of reward processing has been heavily associated with regions in the prefrontal cortex (Krawczyk, 2002; McClure et al., 2004). The orbitofrontal cortex (OFC), a region associated with the ventral prefrontal cortex, has been heavily implicated in reward processing. Based on its subcortical connections within the limbic system, reward processing seems to process information in parallel and overlapping pathways as cognitive control and impulsivity (Krawczyk, 2002). Whereas cognitive control and impulsivity originate in the ventromedial prefrontal cortex and make major subcortical projections towards the anterior cingulate cortex (ACC, also referred to as the midcingulate cortex), reward processing pathways originate in the ventral frontal cortex and project to the ventral striatum and several limbic system structures, including the amygdala and the ACC (Krawczyk, 2002). However, evidence has mostly supported the ventrofrontal-nucleus accumbens-uncus pathway as the recognized stream for reward processing and have referred to the functions of the ACC and the ventromedial prefrontal cortex as more complex and higher order processing regions (for review see Krawczyk, 2002). It is therefore stipulated that reward processing and impulsivity are perhaps opposite sides of the same coin, and that activation within this region has a multimodal role in perception.

The ACC is located in the medial frontal cortex and is the posterior area of the rostral cingulate cortex (Bush et al., 2002; Holroyd & Yeung, 2012). This area is highly interconnected with surrounding areas (Paus, 2001), as such, the ACC is believed to be involved in many different functions and phenomena: effort (Holec, Pirot, & Euston, 2014), motivation (Holroyd & Yeung, 2012), reward prediction error (Holroyd & Coles, 2002), motor control (Paus, 2001), pain perception (Iwata, 2005), etc.

Dopamine is a neurotransmitter associated with movement, attention, pain, and, importantly, rewards (Barter et al., 2015; Benarroch, 2016; Nieoullon, 2002; Schultz, 2015). One of the systems important for reward processing, involving the ACC, is the mesencephalic dopamine system (also known as the midbrain dopamine system). The mesencephalic dopamine system is a group of nuclei in the ventral tegmental area and substantia nigra pars compacta that project to the basal ganglia and frontal cortex (Holroyd & Coles, 2002; Holroyd & Yeung, 2012).

When an unexpected rewarding event occurs, the dopaminergic neurons become highly activated (Schultz, 1998), which functions as a way to report prediction errors to the basal ganglia and other cortical areas in order to drive reinforcement learning (Schultz, Dayan, & Montague, 1997).

The association between dopamine and reward expectation and prediction error was discovered in an influential study by Schultz and colleagues (1997). In their experiment, dopaminergic activity was recorded from the mesencephalic dopamine system in rhesus monkeys while they learned stimulus-cue associations. Schultz and associates revealed that a reward – and the accompanying dopamine release – can become associated with a stimulus once an expectation has been formed. In the absence of the expected reward, phasic dopamine release is attenuated. The ACC receives input from this system in order to determine the task and the level of effort required to execute the task; additionally, it is active during voluntary task selection and is said to be important for high-level planning (Holroyd & Yeung, 2012). The findings of Schultz and colleagues (1998) demonstrates that dopaminergic neurons in the ventral tegmental area and substantia nigra follow similar patterns to models of prediction error and are needed in order to learn to maximize rewards. This reduction in dopamine release, or prediction error, provides a neurochemical and electrophysiological signal that can be recorded in order to determine that a cue-reward association has been learned.

1.2.2 Electroencephalography

Electroencephalography (EEG) is a method to record brain activity, which detects the electrical current produced predominantly by cortical pyramidal neurons (Jackson & Bolger, 2014). When many neurons fire synchronously in response to an event, the associated recorded neural component is known as an event-related potential (ERP; Luck, 2014).

EEG is often employed to observe the reward positivity and other ERP components. The reward positivity is an ERP measured using EEG. Originally termed the error-related negativity, it was believed to be a negative deflection associated with incorrect, relative to correct, responses and error detection (Gehring, Goss, Coles, Meyer, & Donchin, 1993; Miltner, Braun, & Coles, 1997). Since its discovery, it has been known as the feedback error-related negativity, error-related negativity, and feedback related negativity. Further research demonstrated that the component is associated with correct feedback, opposed to incorrect (Holroyd, Pakzad-Vaezi, & Krigolson, 2008), and has therefore been referred to as the reward positivity (Proudfit, 2015). The reward positivity is a positive going component that typically occurs between 240 ms and 340 ms after feedback onset and has a frontocentral topography (Sambrook & Goslin, 2015). The reward positivity is elicited by violations of expectations and is associated with feedback processing in the ACC (Holroyd & Coles, 2002). The ACC receives input from the mesencephalic dopamine system in order to determine the task and the level of effort required to execute the task; additionally, it is active during voluntary task selection and is said to support high-level planning (Holroyd & Yeung, 2012). The reward positivity is believed to be elicited by the ACC in order to modify task performance, and its amplitude is modulated by dopaminergic neurons in the mesencephalic dopamine system (Holroyd & Coles, 2002).

Research has shown that the reward positivity amplitude increases when presented with unexpected rewards (i.e. positive prediction error), and decreases when a reward is expected and not received (i.e. negative prediction error; Bellebaum & Daum, 2008; Williams et al., 2017; Yeung & Sanfey, 2004); however, clinical populations and specific personality traits have been shown to be associated with abnormal reward positivity amplitudes (Donaldson et al., 2019;

Endrass et al., 2010; Holroyd & Umemoto, 2016; Proudfit, 2015; Schmidt, Holroyd, Debener, & Hewig, 2017; Weinberg, Kotov, & Proudfit, 2015).

The following sections and remainder of this thesis will focus on concepts and tasks relating to delay discounting and time estimation. Delay discounting is a common feature of impulsivity and is characterized by heightened reward sensitivity and the desire for immediate gratification, despite the presence of higher future rewards (Arce & Santisteban, 2006). Additionally, people with high levels of impulsivity have been found to have abnormal time estimation and perception abilities, often overestimating the passage of time (Moreira, Pinto, Almeida, & Barbosa, 2016), which is thought to contribute to heightened delay discounting and an altered sense of time (Wittmann & Paulus, 2008).

1.3 Delay Discounting

Individuals often make the counterintuitive choice to accept smaller immediate rewards, rather than waiting for larger future ones – known as delay discounting – as they value the current reward higher (Carter, Meyer, & Huettel, 2010; Cherniawsky & Holroyd, 2013). Delay discounting has been described as individuals adjusting their subjective value of a reward due to the large amount of time between learning about and receiving the reward (Carter et al., 2010). This has been associated with obesity, gambling addiction, and substance abuse; moreover, individuals who have higher rates of delay discounting are more likely to begin and continue making decisions with immediate, but not long-term, rewards (Bari & Robbins, 2013). For example, delay discounting rates have been observed to be larger for heroin addicts, compared to controls, and were positively correlated with impulsivity levels (Kirby, Petry, & Bickel, 1999).

1.3.1 Behavioural Studies

Like heroin addicts, children are also known to make impulsive choices. Some earlier research in delay discounting has been conducted (Mischel, 1973; Mischel & Ebbesen, 1970; Schack & Massari, 1973), but knowledge on this topic became widespread with the seminal 1988 paper by Mischel and colleagues. In this paper, the authors describe a study conducted on pre-school age children, examining their ability to delay immediate gratification – by not consuming a marshmallow – in order to receive a better reward (i.e. an additional marshmallow) from the researcher. Importantly, children in their study who were able to delay gratification later became adolescents with lower levels of impulsivity, more self-control, rational, attentive, and socially and academically competent (Mischel, Shoda, & Peake, 1988). Additionally, these adolescents became adults with augmented behavioural regulation abilities. The same pre-school children who were unable to delay gratification (i.e. displayed higher delay discounting) in the Mischel et al. (1988) paper, were found to have more activation in their ventral striatum (i.e. otherwise known as the nucleus accumbens) while performing cognitive control tasks as adults (Casey et al., 2011). Further research on the same sample of pre-school age children found that their ability to delay gratification was associated with body mass index 30 years later; moreover, young girls able to delay consuming the marshmallow were found to have lower weights as adults (Schlam, Wilson, Shoda, Mischel, & Ayduk, 2013).

Despite the findings reported by Mischel and colleagues (1988), these results have recently been challenged. A conceptual replication conducted by Watts, Duncan, and Quan (2018) attribute other factors to later success. In order to have a more generalizable sample, the researchers focused on children of mothers who do not hold a college degree, rather than from parents who worked and/or studied at an ivy league institution, as examined by Mischel et al. (1988). Watts and colleagues observed that future achievement during adolescence was associated more with family background, home environment, and early intellect than with the ability to delay gratification in a modified marshmallow task. Nevertheless, requiring children to delay gratification for only seven minutes (compared to the 20 minute delay in the original Mischel and colleagues (1988) study) in order to obtain a better reward, Watts and associates did find that the ability to delay gratification accounted for a small portion (effect size = 0.222) of the effect.

Contrary to the recent Watts et al (2018) study, the findings by Mischel and colleagues (1988) have been replicated extensively by others in humans (Caspi, Moffitt, Newman, & Silva, 1996; Duckworth, Tsukayama, & Kirby, 2013; Funder, Block, & Block, 1983; Kidd, Palmeri, & Aslin, 2013; Lengua, 2003; Moffitt et al., 2011), non-human primates (Beran, Savage-Rumbaugh, Pate, & Rumbaugh, 1999; Parrish et al., 2014; Pelé, Micheletta, Uhlrich, Thierry, & Dufour, 2011; Stevens, Rosati, Heilbronner, & Mühlhoff, 2011), and rodents (Reynolds, de Wit, & Richards, 2002; Wade, de Wit, & Richards, 2003). Specifically, Lengua (2003) conducted a modified delay of gratifiaction task, where older children (i.e. seven to 11 years old) were given an unknown toy in a box and were tasked with waiting for a better toy. In accordance with the study by Mischel et al (1988), Lengua (2003) also found that difficulty delaying gratification was associated with worsened social competencies in adolescents. When examining gender differences in the ability to delay gratification, no difference in waiting times were found in four year old children; however, when their behaviour was examined at age 11, boys and girls were described differently by teachers (Funder et al., 1983). In this study, boys who were able to delay gratification were described as deliberate, attentive, focused, emotionally controlled, cooperative and reserved, while girls were portrayed as intelligent, resourceful and competent. Additionally, the boys who were unable to delay gratification were thought to be irritable, restless, aggressive, and lacked control; moreover, girls in this group were believed to not handle stress well, be victimized, easily offended, sulky, and whiny (Funder et al., 1983). This shows that despite there being no gender differences in delay time, the participants personalities were viewed differently depending on gender. Further study into the lasting implications of delaying gratification as a young child found that longer delay times were associated with better grades, lower body mass index, and fewer risky decisions (Duckworth et al., 2013). Additional investigation into delaying gratification revealed that experimenter reliability effected the child's delay time; furthermore, children with reliable experimenters delayed gratification for longer than those with an unreliable experimenter, showing that the children held beliefs about their environmental reliability and this altered their decision making process (Kidd et al., 2013). Another longitudinal investigation was also performed, following participants from birth until the age of 32 (Moffitt et al., 2011). Researchers observed that self-control and the ability to delay gratification in childhood functions as a predictor of adult physical health, substance use, finance, and criminal behaviour (Moffitt et al., 2011).

Delay discounting is observed in adults as well as children. Research examining the effects of delay discounting of money and alcohol in current alcoholics, abstinent alcoholics, and control subjects has found that all groups rated the subjective value of money and alcohol as lower as the intertemporal delay increased (Petry, 2001). This study also observed that regardless of condition, current alcoholics discounted both alcohol and money at a faster rate than both other groups; surprisingly, they discounted alcohol at a higher degree than money. The author found that each group differed in terms of their impulsivity scores and these scores were correlated with discounting rates for money, but not alcohol. Petry suggests that alcohol may be discounted differently than money, due to the lower subjective value of alcohol, compared to the monetary values offered. Another explanation offered was that alcohol discounting may be affected by the current desire for alcohol. A similar study has also been conducted on cocaine-dependent individuals with the same pattern of results (Coffey, Gudleski, Saladin, & Brady, 2003). Coffey and colleagues (2003) found that cocaine-dependent participants discounted money at a higher rate than controls, and discounted cocaine more than money. As expected, the cocaine-dependent subjects had higher levels of impulsivity on two different self-report measures of impulsivity. Additionally, the same pattern of disparity between immediate and future rewards has also been observed in highly impulsive individuals (Guan & He, 2018). Literature examining state self-control found that individuals with low levels of trait self-control were more likely to select the immediate, rather than delayed, reward when their levels of cognitive control were depleted; however, this was not the case prior to performing challenging cognitive control tasks (Guan & He, 2018).

Another question is how delay discounting changes across the lifespan. One study examining delay discounting focused on participants age ten to 30 years old (Steinberg, Graham, Woolard, Cauffman, & Banich, 2009). Steinberg and colleagues found that delay discounting rates were higher in younger participants (i.e. ten to 15 years old) and improved with age. Other researchers also examined delay discounting at different ages, ranging from nine to 101 years old (Göllner, Ballhausen, Kliegel, & Forstmeier, 2018). In line with the above researcher, they also observed that delay discounting rates were highest for children (i.e. nine to 14 years old) and older adults (i.e. 65 and over), and lower for young and middle adults. This correlates with intelligence, which is lowest in childhood and old age (Göllner et al., 2018).

1.3.2 Neural Regions.

Imaging and lesion studies have also been conducted to uncover the biological aspects of delay discounting. While examining decision cost, Rudebeck and Murray (2014) lesioned two areas of the rat brain in isolation: the ACC and orbitofrontal areas. They observed that lesioning the ACC decreased the amount of effort a rat was willing to invest in a reward (also see Holec, Pirot, & Euston, 2014); importantly, lesioned orbitofrontal areas influenced the delay in which the rat was willing to wait for the larger reward. Additionally, when effort is involved, impulsive people have been found to select the less effortful option (Massar, Libedinsky, Weiyan, Huettel, & Chee, 2015). This finding suggests that impulsivity may be associated with atypical neuroanatomical features.

An additional lesion study in rats found that reward discounting, as a function of delay, was potent when the ventral striatum was lesioned (Cardinal, Pennicott, Sugathapala, Robbins, & Everitt, 2001). Recent animal and human studies found that immediate rewards were closely associated with increased activity in the ventral striatum, medial prefrontal cortex, and OFC; additionally, delayed rewards were positively correlated with activity in the lateral prefrontal cortex and, unexpectedly, the OFC (Dalley et al., 2011). Similarly, in an intertemporal delay task conducted while the fMRI BOLD response was being recorded, certain neural regions were sensitive to the subjective value of rewards: the medial prefrontal cortex, posterior cingulate cortex, and ventral striatum (Sripada, Gonzalez, Luan Phan, & Liberzon, 2011). They also found that slightly different areas were associated with the immediate reward being present: the medial prefrontal cortex and posterior cingulate cortex.

In 2013, Cho and colleagues used fMRI to observe a positive correlation between impulsivity and activation of the left ACC along with the dorsolateral prefrontal cortex; while, others found activity to be associated with bilateral activation of ventral striatum, OFC, lateral and medial prefrontal cortex, subthalamic nuclei, insula, and other regions (Costa Dias et al., 2013; Hahn et al., 2009; Hinvest et al., 2011; MacKillop et al., 2012; Mechelmans et al., 2017; Sripada, Gonzalez, Luan Phan, & Liberzon, 2011; Wilbertz et al., 2012). Some researchers attribute the increased activation in reward associated areas with reward anticipation (Hahn et al., 2009), while others found that activation increases with subjective valuation (Sripada et al., 2011). Additional research has found that activation in the ventral striatum is not only associated with reward choice, but also while awaiting the reward (Jimura, Chushak, & Braver, 2013). This feature of impulsivity is also associated with decreased connectivity between the ventral striatum and the insula, ACC, middle temporal cortex, and parietal regions (Costa Dias et al., 2013).

1.3.3 Electroencephalography and Delay Discounting.

How we value current and future rewards is imperative for goal setting and achievement, because rewards have a motivational effect. In order to examine the effect of delay discounting on emotional processing, Blackburn, Mason, Hoeksma, Zandstra, and El-Deredy (2012) used EEG in conjunction with a behavioural delay discounting task. In the task, participants were presented with either rewards or penalties immediately, after one week, or one month following the experiment. The researchers found that the delayed rewards were associated with an attenuated reward positivity, which decreased with reward delay. Blackburn and colleagues attribute this finding to decreased incentive value and emotional saliency associated with delayed rewards. In a similar delay discounting task, Qu, Huang, Wang, and Huang (2013) examined the effect of either a monetary gain or loss on reward positivity amplitude. In accordance with the findings of Blackburn et al. (2012), Qu and associates also found a reduced reward positivity amplitude following delayed rewards.

To further explore these findings, Zhao and associates (2018) utilized an intertemporal decision-making task. In this procedure, participants made binary choices between two options, each specifying a reward value and a delay that must be waited prior to receiving the reward. In this experiment, reward delay ranged from no wait, to up to six weeks. On average, they found that participants preferred small, immediate, rewards over larger, future, rewards. Zhao and his team found that P200 component – associated with attention – was smaller for small, immediate, rewards, compared to larger and delayed rewards, which the authors propose is related to more unconscious attention being paid to the larger reward. In contrast, the N200 ERP component – typically associated with conflict – was related to negative emotions and was augmented in the loss, compared to the win conditions (Zhao et al., 2018).

Delay discounting and delayed gratification tasks are often seen as tests that measure impulsivity levels. This is because forgoing a large future reward in light of a smaller and current reward is often viewed as inherently impulsive (Ainslie, 1975). This common belief results in few studies examining delay discounting disparate from impulsivity, something that Harrison, Lau, and Williams (2002) think should occur more frequently.

To date, little work has been done to examine how impulsivity impacts the electroencephalographic correlates of human reward processing in general; however, delay discounting has been thoroughly studied using EEG, providing consistent results (Cherniawsky & Holroyd, 2013; Gu et al., 2017; Mavrogiorgou et al., 2017; Novak, Novak, Lynam, & Foti, 2016; B. Schmidt et al., 2017). Cherniawsky and Holroyd (2013) found a correlation between impulsivity and valuing immediate rewards higher than future rewards, as assessed with an intertemporal decision-making task, which can be observed as a larger amplitude reward positivity – an EEG component associated with rewards – in response to immediate rewards

(Cherniawsky & Holroyd, 2013; B. Schmidt et al., 2017). In their study, Cherniawsky and Holroyd (2013), had participants complete a written questionnaire assessing their delay discounting tendencies, and later performed a computer-based task where they either received immediate or delayed rewards. They found that individuals who were more likely to select the immediate reward, rather than delaying gratification, in the written questionnaire had an augmented reward positivity amplitude to immediate rewards in the computer task. This suggests that group that prefers immediate gratification is overvaluing the immediate reward, rather than undervaluing future rewards. In a following study, impulsivity – assessed with questionnaires – was found to correlate positively with reward positivity amplitude; where immediate rewards elicited a larger reward positivity in highly impulsive individuals (Schmidt et al., 2017). The larger reward signal to immediate gratification would contribute to the ACC releasing control over delayed rewards, allowing the individual to act impulsively and accept the immediate reward (Schmidt et al., 2017). Interestingly, other researchers found that adolescents and adults both value immediate rewards similarly; however, adolescents undervalue future rewards more than adults (Huang, Hu, & Li, 2017). This effect is attributed to adolescent impulsivity and was concluded based on reward positivity amplitude, where adolescents had reduced reward positivity amplitudes, compared to adults, in response to delayed rewards.

1.4 Time Estimation

As discussed above, the preference for immediate gratification in impulsive individuals is a highly replicated and robust finding. However, less known is why these people prefer immediate rewards, over objectively larger, but delayed, rewards. In an attempt to answer this question, Wittmann and Paulus (2008) propose a theory wherein they posit that impulsive people overestimate the passage of time due to abnormal time perception, which leads them to discount rewards at an abnormally high rate. As discussed in their paper, both delay discounting and the overestimation of time have been extensively found in highly impulsive individuals. Time estimation and perception are not unitary constructs and, as such, have been extensively examined using many different tasks across the lifespan.

1.4.1 Behavioural Studies.

The question of how individuals perceive and estimate the passage of time has been pondered for centuries. In the late 19th and early 20th centuries, researchers began examining time estimation differences during various stages of infancy, up to adulthood. Specifically, Axel (1924) examined the effect of age and different distractor tasks on time estimation ability. Each participant competed four tasks, where one trial of a task lasted for the duration of 15 to 40 seconds. The first task required participants to do nothing but wait. Following each experimental trial, for all tasks, participants wrote down an estimate of how long they had waited during said trial. The following task required children to write as many "I's" as possible, or to tap a pad of paper a specific way for adults. For the third task, participants were given a list of numbers and crossed out every five; furthermore, the fourth and final task required subjects to do mental addition. From this simple task, Axel observed that younger participants (i.e. nine to 14 years old) performed better when they were engaged in the activity and when experiencing shorter times, as in tasks two through four. Interestingly, adults (i.e. 17 to 52 years old) were better at estimating the duration of longer times and when not preoccupied or distracted. When performing no task or tapping, participants consistently overestimated the passage of time, but underestimated during the other tasks (Axel, 1924). Other researchers corroborated that time intervals above 30 seconds were often overestimated (Myers, 1916; Swift & McGeoch, 1925).

Further examining the effect of distraction on time estimation, Postman (1944) had participants complete three distractor tasks, after each task subjects had to estimate the length of time that was spent on said task. The first task required the participant to perform addition problems, the next required subjects to cross out specific letters on a mimeographed sheet, and the final task had participants fill in the missing letters on a mimeographed sheet of newspaper clippings. These tasks were counterbalanced and lasted either three, five, or seven minutes. Postman found that regardless of the task, subjects consistently overestimated the passage of time, with the second task always overestimated more than the others.

Individuals perceive the world around them in unique ways. As previously discussed, impulsivity can alter the perceived value of a reward, and is it posited to result in an altered sense of time. Wittmann and Paulus (2008) propose a theory that abnormal delay discounting is the result of an altered sense of time, suggesting that impulsive people overestimate the passage of time, leading them to discount rewards at a faster rate. For example, when thinking of the future impulsive people may perceive three days as seven, leading them to discount rewards at a higher than expected rate. When making a choice, the value of immediate gratification is taken into account, as well as the cost associated with waiting for a reward; additionally, when the perception of time is altered and perceived as moving too slowly, then the cost associated will also be too high.

Time estimation requires the participant to estimate when a specific duration of time has passed (e.g. how long did the stimulus remain on the screen?) (Berlin, Rolls, & Kischka, 2004). When time production and perception studies were performed on impulsive individuals, adolescents were found to underproduce time intervals between one and ten seconds, which was rationalized as participants perceiving the passage of time as a slower rate (Barratt, 1981). When assessed based on their ability to match, maintain, and later produce tapping at a paced rate or tempo, impulsivity was found to correlate positively with tapping rate (Barratt, Patton, & Greger Olsson, 1981); additionally, these researchers posit that individuals with augmented impulsivity levels also have difficulty in complex information processing (e.g. when feedback in involved), resulting in lower tapping accuracy. Time estimation and perception tasks have revealed that impulsivity is positively correlated with the overestimation of time during short (i.e. under one minute) and long intervals (i.e. over one minute; Berlin et al., 2004; Berlin & Rolls, 2004; Corvi, Juergensen, Weaver, & Demaree, 2012; Havik et al., 2012; Moreira et al., 2016; Schulreich, Pfabigan, Derntl, & Sailer, 2013; Wittmann et al., 2011; Wittmann & Paulus, 2008). Specifically, Havik and colleagues (2012) examined the influence of impulsivity on time estimation in healthy participants with the aid of a pattern test. Participants viewed a slideshow, with each slide containing a different visual pattern, and the individuals were tasked with estimating how long they viewed each slide. Each slide was presented for three seconds. As in the aforementioned studies, results indicated that impulsivity levels were positively correlated with length of time estimated; therefore, high impulsivity individuals overestimated the length of time that the slide was viewed.

Until this point, we have seen evidence that short time intervals are consistently overestimated by highly impulsive individuals, but the question of whether this pattern applies to longer time intervals remains. In an attempt to answer this question, Berlin and associates (2004) explored the effect of orbital frontal cortex (OFC) dysfunction on impulsivity, time production, and estimation tasks. Damage to the OFC has been associated with increased impulsivity, and this study compared individuals with and without OFC lesions. Participants completed three tasks: (1) durations of 10, 30, 60, and 90 seconds were estimated; (2) time production, where participants said “Stop” after a certain number of seconds has passed, they were distracted by reading numbers aloud during this task; and (3) long-term estimation required subjects to estimate the duration of the experiment. Berlin and his colleagues observed that individuals with OFC damage were more impulsive, overestimated and underproduced time intervals; furthermore, this led the researchers to conclude that OFC damage and impulsivity were associated with an increased sense of time. The pattern of overestimation of time for longer durations was also replicated by Corvi and associates (2012).

Impulsivity is not the only factor that can cause temporal distortions. Individuals with fear and anxiety disorders have been observed to overestimate the passage of time in the presence of fear or anxiety inducing stimuli (Buetti & Lleras, 2012; Lake, Labar, & Meck, 2016).

1.4.2 Neural Regions.

Using fMRI, researchers found that the inferior and medial frontal cortices, anterior insula, and inferior parietal cortex were associated with the overestimation of time (Wittmann et al., 2011). Berlin et al. (2004) also found that patients OFC lesions had greater levels of self-reported impulsivity and overestimated time intervals. While investigating the effects of medications on timing, researchers found that the nigrostriatal dopamine system (i.e. substantia nigra and dorsal striatum) was responsible for timing sensitivity (Coull et al., 2011).

In a review, Coull et al. (2011) examined the neuroanatomical and neurochemical correlates of time estimation. They found that the supplementary motor area, cerebellum, prefrontal cortex, and basal ganglia were all involved in time estimation; although, their implications in time estimation are task dependent. In light of this, Coull and colleagues concluded that the ascending nigrostriatal dopaminergic pathway is the most crucial of these regions for timing, because low levels of dopamine in rats was associated with timing deficits (Meck, 2006).

1.4.3 Electroencephalography and Time Estimation.

Time perception is a subjective concept and the study of an individual's ability to estimate and reproduce a time interval has waxed and waned for over a century; however, examining the neural correlates of time estimation is a relatively new idea. Furthering this field of research, a seminal study conducted by Miltner, Braun, and Coles (1997) investigated participants' ability to estimate time and the associated neural correlates. In this experiment, subjects were tasked with estimating the length of one second. Research has shown that participants consistently overestimate the duration of one second and their performance and reward positivity amplitude on this task was not affected by feedback modality (i.e. somatosensory, auditory, and visual; Miltner et al., 1997). Individuals in the study were also observed to change their response times more after negative than positive feedback, indicating that following negative feedback (i.e. a loss trial) participants changed their behaviour in order to improve task performance, something that was not done after receiving positive (i.e. win trial) feedback. This task has since been replicated and extended by several studies, finding that the reward positivity was associated with task difficulty and expectation (e.g., Holroyd & Krigolson, 2007; Williams, Hassall, Trska, Holroyd, & Krigolson, 2017).

Importantly, researchers have yet to examine the influence of impulsivity on time estimation in conjunction with ERPs. This is something that I will explore in this paper's second study.

1.5 The Current Experiments

Impulsivity encompasses behaviours with a wide range of implications, many of which lessen with age and the continuation of typical neural development. When typical neurodevelopment cannot occur, abnormal levels of neurotransmitters contribute to impulsive behaviour and affect how individuals make decisions about their present, future, and even how the passage of time is perceived. Despite being extensively examined behaviourally, the neurological signatures of impulsivity remain controversial.

This thesis will focus on how impulsivity levels modulate performance and reward positivity amplitude in the delayed gratification and time estimation tasks. Importantly, each participant's impulsivity score – measured using the BIS-11 – was collected prior to participating, and all subjects fell into the high or low impulsivity level as recommended by Stanford et al. (2009). Delay discounting and time estimation were used in order to explore the theory proposed by Wittmann & Paulus (2008), who posit that impulsivity is associated with an altered perception of time, which leads to abnormal delay discounting behaviour. In order to test this theory, I first determined the presence of abnormal delay discounting, prior to examining time estimation. The time estimation task was also used as a separate measure of reward processing – one that does not involve monetary reward – and to determine if impulsivity is associated with an altered sense of time. Despite the robust finding of altered time estimation in impulsive individuals, this has yet to be assessed in conjunction with EEG. Using EEG, I examined the neural correlates associated with reward processing in each task in order to increase our understanding of this personality trait, in terms of how time estimation influences delay discounting, and help explain why many impulsive people often desire immediate gratification, leading them to eventual substance abuse and problematic gambling behaviours.

The impulsivity characteristic of interest, delay discounting, was examined using a delayed gratification task and a time estimation task, which are examined as separate studies in this paper. For the delayed gratification task, I hypothesized that the high impulsivity group would have faster response times and an increased reward positivity amplitude in response to immediate and larger rewards, than to smaller and delayed rewards; furthermore, this is predicted due to abnormal reward processing – observed by augmented reward positivities to immediate rewards – which has been seen in this task by others (Cherniawsky & Holroyd, 2013; Gu et al., 2017; Mavrogiorgou et al., 2017; Novak et al., 2016). The delayed gratification task is a replication based on the paper by Schmidt et al. (2017) and will serve to verify the distinctness of the experimental (i.e. high impulsivity) from the control group (i.e. low impulsivity). Based on previous research examining time estimation and impulsivity (Berlin et al., 2004; Berlin & Rolls, 2004; Corvi et al., 2012; Havik et al., 2012; Moreira et al., 2016; Schulreich et al., 2013; Wittmann et al., 2011; Wittmann & Paulus, 2008), I predict that accuracy in the time estimation task, as measured by window bound size, will be negatively associated with impulsivity level. I also hypothesize that impulsivity will be associated with an attenuated reward positivity amplitude, due to previous associations between impulsivity and decreased dopamine release (Dalley et al., 2011; Morgan et al., 2002). The second task, time estimation, has not been examined in conjunction with ERPs and impulsivity. Importantly, these two tasks were conducted as part of a larger task battery, involving five tasks. Following the results and discussion of each task, a new perspective is introduced, positing that each reward task is examining distinct underlying reward processes. Explanations for the findings are given.

Chapter 2: Delay Discounting

2.1 Introduction

When offered the choice between \$10 now or \$100 in two weeks, most individuals would opt for the latter option, given the high payoff following a short interval. However, people often make the counterintuitive choice to accept smaller immediate reward, rather than waiting for larger future one. This is known as delay discounting, and is thought to result from overvaluing the current reward, regardless of its lesser magnitude (Carter et al., 2010; Cherniawsky & Holroyd, 2013). The tendency to discount future rewards has been associated with obesity, gambling addiction, the desire for immediate gratification, and substance abuse. Knowledge on this topic became widespread with the seminal 1988 paper by Mischel and colleagues. In this paper, the authors examine the ability of pre-school age children to delay immediate gratification. They found that children able to wait, became adolescents with lower levels of impulsivity, more self-control, rational, attentive, and socially and academically competent (Mischel et al., 1988); moreover, they later became adults with enhanced behavioural regulation abilities (Casey et al., 2011) and had a lower body mass index (Schlam et al., 2013).

The aforementioned behavioural experiments only account for part of the story, while neuroimaging is required to observe the rest. The phenomena of delay discounting has been thoroughly studied using electroencephalography (EEG), providing consistent results (Cherniawsky & Holroyd, 2013; Gu et al., 2017; Mavrogiorgou et al., 2017; Novak et al., 2016; Schmidt et al., 2017). In a delayed discounting task, participants selected between two hypothetical monetary rewards, one of which would be given immediately while the other is associated with a temporal delay. Following this task, participants were presented with a T-maze, wherein they would either win 25¢ or 1¢ now, or after one month (Cherniawsky & Holroyd, 2013). The aim of the task was for the participants to make as much money as possible. Cherniawsky and Holroyd (2013) found a correlation between behavioural discounting of rewards and valuing immediate rewards higher than future rewards, which can be observed as a larger amplitude reward positivity – an EEG component associated with rewards – in response to immediate rewards (Cherniawsky & Holroyd, 2013; Schmidt et al., 2017). This suggests that individuals with high levels of impulsivity are overvaluing immediate rewards, rather than undervaluing future rewards.

In a subsequent study, Schmidt and colleagues (2017) examined impulsivity in a delayed gratification task. In their study, participants were presented with four cards, face-down. Once selected, the card would turn over to reveal either a small or larger reward that would be received now or after a six-month delay. This paper found that impulsivity (measured by combining both an impulsivity and self-control questionnaire) was positively correlated with reward positivity amplitude in delayed gratification task and that highly impulsive individuals had a larger reward positivity difference between immediate and delayed rewards than the low impulsivity group. The larger reward signal to immediate gratification is thought to contribute to the ACC releasing control over delayed rewards, allowing the individual to act impulsively and accept the immediate reward (Schmidt et al., 2017)

Here, I sought to replicate previous findings examining how impulsivity modulates reward processing in a delayed reward environment. Using the Barratt Impulsiveness Scale (BIS-11), I have identified two distinct groups of people, one with impulsivity scores higher than average (i.e. high impulsivity group) and another with scores lower than the population average (i.e. low impulsivity group). I was specifically interested in the reward processing mechanisms involved when small and large rewards are given with intertemporal delay, and subsequently how the reward positivity is affected by this. Importantly, the task functioned as a way to determine if my two impulsivity groups were distinct from each other. Based on previous research (i.e. Gu et al., 2017; Mavrogiorgou et al., 2017; Novak et al., 2016; Schmidt et al., 2017), I hypothesize that impulsivity level will influence response times and the reward positivity amplitude between immediate and delayed rewards. Specifically, the high impulsivity group is anticipated to have faster response times and a larger reward positivity amplitude in response to immediate and larger rewards, than to smaller and delayed rewards.

2.2 Method

2.2.1 Participants.

Sixty undergraduate students from the University of Victoria participated in this study. Data from five participants were removed from post-experiment analyses due to an excessive number of artifacts (> 25 %), leaving 55 useable subjects (16 male, $M_{\text{age}} = 20.4$ [95% CI: 19.6, 21.2]). All participants volunteered and were recruited from the University of Victoria Psychology Research Participation System and were compensated with course credit in a psychology course. A subset of the participants was recruited from an additional University of Victoria experiment, where one of the questionnaires completed in the experiment was the Barratt Impulsiveness Scale, Version 11 (BIS-11). Ethical approval was obtained in order to receive the participants BIS-11 scores. Participants were categorized into one of two groups (group cutoff scores suggested by Stanford et al., 2009): the low impulsivity group (BIS-11 composite scores under 52, $M = 47.8$ [46.8, 48.8]) or the high impulsivity group (BIS-11 scores higher than 71, $M = 79.2$ [76.6, 81.7]). When recruited and during participation, subjects were unaware that impulsivity was being examined, and were informed that I was assessing personality traits of interest. All subjects had normal or corrected-to-normal vision. Prior to commencing the experiment, every participant provided informed consent in agreeance with the guidelines established by the University of Victoria and followed the ethical standards specified in the 1964 Declaration of Helsinki. Prior to beginning the task, students were informed that they would be receiving a monetary reward, part of which they would receive immediately following the experiment, and the remainder after one month had passed; however, following the experiment, they were clearly informed that they would receive all of their earnings immediately following the end of the study. The students also received $6.50 each, which they won based on performance in the delayed gratification task.

2.2.2 Procedure and Apparatus.

The experiment was conducted in a sound dampened room, where participants were seated in front of a 19-inch LCD computer monitor and used a ResponsePixx (VPixx Technologies, Saint-Bruno, Canada) button box to make their responses in the delayed gratification task. The task was programmed in MATLAB (Version R2017b, Mathworks, Natick, USA) using the Psychophysics Toolbox extension (Brainard, 1997)..

Delayed Gratification Task

During the delayed gratification task (based on Schmidt et al., 2017), participants were first presented with task instructions, where they learned that they would see four cards, each of which had feedback associated with it (see Figure 2.21a). Subjects read that they would either receive a larger sum of money (i.e. 10 cents) immediately or after one month. Or, they would receive a smaller monetary reward (i.e. 1 cent) immediately or after one month. The meaning of the feedback stimuli was counterbalanced across participants.

To commence each trial, subjects were presented with a black fixation cross for a varied amount of time (300 to 700 ms) which was followed by the appearance of four cards – in addition to the fixation cross – face down. After approximately 400 ms, the fixation cross would become white, and participants had up to 1500 ms to make their card selection. Once selected, the face of the card was revealed with feedback for 1500 ms (see Figure 2.21). All stimuli in the delayed gratification task occupied approximately 9° of visual angle vertically and 7° horizontally. Participants completed four blocks of 60 trials. Feedback was pseudorandomly presented so that each outcome occurred with equal frequency. This task was performed as part of a larger test battery.

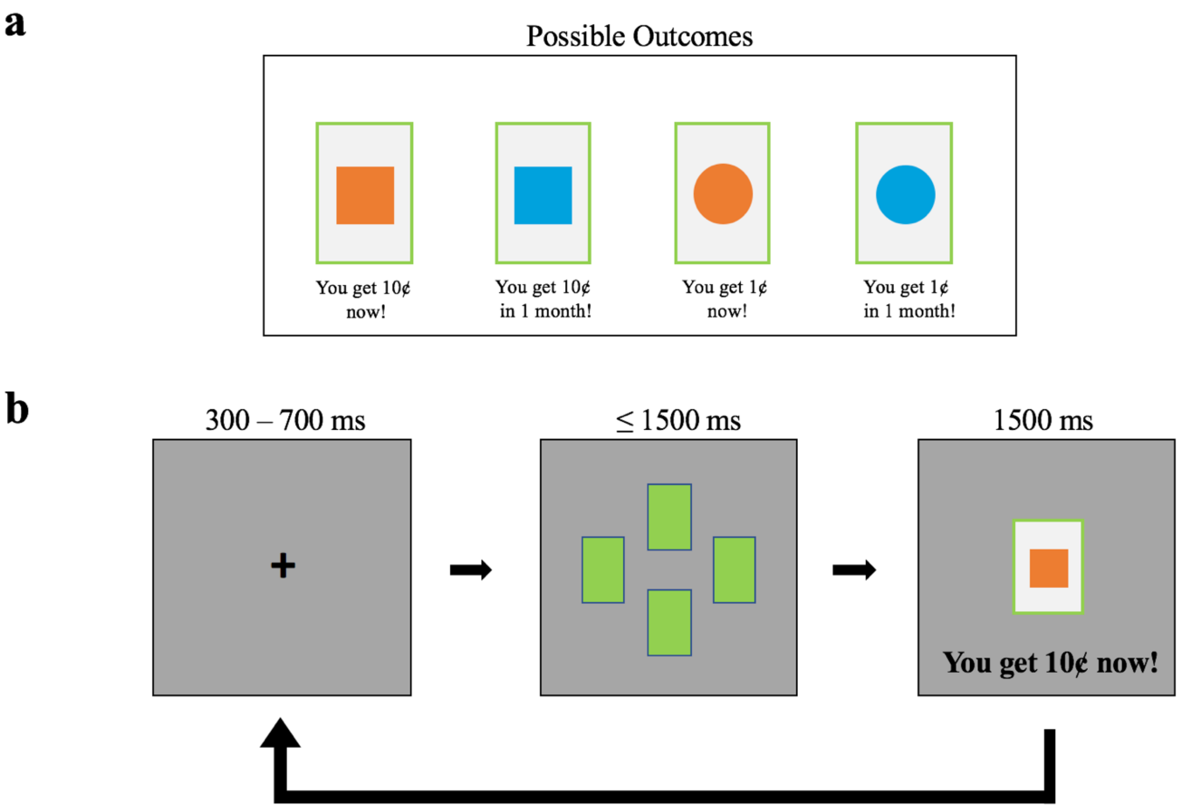


Figure 2.21. The delayed gratification task. (a) the four possible outcomes of card selection. (b) an example of one trial. A fixation cross is presented, followed by four cards face down, a card is selected, and the reward amount and timing are revealed.

2.2.3 Data acquisition.

Card selected and response time (ms) data were logged using MATLAB (Version R2017b, MathWorks Inc, Natick, USA). EEG data were recorded from 32 active electrodes, mounted in a 10-20 layout fitted cap (ActiCAP, Brain Products GmbH, Munich, Germany), using Brain Vision Recorder software (Version 1.21.0201, Brain Products GmbH, Munich, Germany). All electrodes were referenced to electrode AFz during recording. EEG data were recorded at a 500 Hz sampling rate, amplified (ActiChamp, Revision 2, Brain Products GmbH, Munich, Germany), and filtered through a low-pass filter at 8 kHz to prevent aliasing.

2.2.4 Data analysis.

In the delayed gratification task, participant's response times were averaged, so that there was a mean response time for each impulsivity group. ERP data were analyzed using a three by two mixed analysis of variance (ANOVA). The ANOVA was performed on participant's averaged peak data, with reward magnitude and feedback delay as within subject factors and impulsivity levels – based on composite BIS-11 scores – as a between subject's factor. This was followed by the calculation of effect size – as measured by eta squared – which is preferable to partial eta squared for its generalizability (see Levine & Hullett, 2002). Paired and independent samples *t*-tests were then performed post hoc. Following each comparison, 95% confidence intervals were calculated. The use of effect sizes and confidence intervals were included, as they are more informative than *p*-values and standard deviation alone (see Cumming, 2013). Effect sizes and confidence intervals describe the size of the effect and give a range of where the actual population means lies, rather than stating if two groups differ. Importantly, the use of *p*-values alone can lead to the misinterpretation of findings and the inability to replicate previous research (Schmidt & Rothman, 2014). The main type of statistics used here are p-values, but other statistics, including correlations, effect sizes, and confidence intervals were also used in an exploratory manner in order to gain further insight into my data. The implications of these are discussed in the general discussion. Correlational analysis was also performed on the reward positivity amplitude, relating each participant's BIS-11 score to their reward positivity amplitude for both immediate and delayed rewards, as well as an average reward positivity for the task. This was achieved by averaging all reward positivity amplitudes per participant. Correlation, as measured by Pearson's *r*, was also computed between reward delays, and between reward delays and averaged task reward positivity.

All EEG data were processed using Brain Vision Analyzer (Version 2.1, Brain Products GmbH, Munich, Germany). Continuous EEG data for each participant and channel were visually inspected and channels were removed if noisy or faulty. The sampling rate of the data were reduced to 250 Hz, and continuous data were re-referenced to the average of the mastoid channels (TP9, TP10). A dual-pass phase free Butterworth filter with a band-pass of 0.1 Hz to 30 Hz and a step of 24 dB/oct, and a 60 Hz notch filter were applied. Segments were then created from the continuous EEG data, which encompassed 1000 ms before and 2000 ms after feedback stimuli onset. The long epochs were then put through independent component analysis (ICA), a transformation which I used to identify and remove ocular artifacts (Luck, 2014). A restricted infomax ICA with classic PCA sphering was applied, and the processing proceeded until a convergence bound of 1.0×10^{-7} or 512 steps had been reached. Following ICA, visual examination of the factor loadings and component topography were conducted, in order to select components to be removed that contain eye blinks, which was conducted using the inverse ICA transformation. Data were reconstructed following inverse ICA, and removed channels were interpolated via the spherical splines method. At this stage, all ERP data were exported to MATLAB for further processing. Once in MATLAB, all segments were baseline corrected from 200 ms prior to feedback stimuli onset using EEGLAB software (Version 14.1.1, Swartz Center for Computational Neuroscience, La Jolla, USA). All epochs were then further segmented by condition, participant group, and feedback valence into shorter epochs, ranging from 200 ms prior to 600 ms after the response. Subsequently, all segments were submitted to an artifact rejection algorithm, which removed segments of data with gradients larger than 10 µV/ms or an absolute difference of more than 100 µV within a segment. An average of 10.15 percent (CI = [8.4,11.9]) of the data was lost.

Following artifact rejection, high and low reward segments from the delayed gratification task were averaged separately for the immediate and future reward conditions, as well as for high and low impulsivity levels, to create averaged ERP waveforms. Difference waves were then created for each participant by subtracting the average low reward from the average high reward waveforms between impulsivity groups and within reward delays. This created four different reward positivity waveforms: (1) high impulsivity, immediate reward; (2) high impulsivity, delayed reward; (3) low impulsivity, immediate reward; and (4) low impulsivity, delayed reward. Grand average waveforms were computed for all conditional waveforms by averaging the corresponding individual waveforms. In order to determine the scalp distribution of the reward positivity, individual participant scalp topographies for mean peak reward positivity in each condition and outcome were averaged. Mean peak amplitude per person was determined by locating the peak latency, and amplitude, and averaging the amplitude for 25 ms on either side of the peak. This was then averaged together for each condition. For all feedback conditions and outcomes the reward positivity amplitude was measured as the maximal peak amplitude between 240 and 340 ms (as suggested in the meta-analysis by Sambrook & Goslin (2015)) in the average participant waveforms following the onset of feedback stimuli. This was measured at channel FCz, where maximal deflection occurred and the scalp topography was observed to be frontocentral in accordance with the literature (Proudfit, 2015).

2.3 Results

2.3.1 Behavioural Data

First, I examined response time differences between the high and low impulsivity groups in the delayed gratification task in order to determine the existence of group differences. The analysis of performance found that impulsivity did not affect response time ($M_{\text{High}} = 489.05$ [437.13, 540.98], $M_{\text{Low}} = 515.96$ [473.49, 558.44], $t(53) = -0.23$, $p = 0.41$). Due to the nature of the task – where participants unknowingly received pseudorandom feedback – no accuracy differences exist between groups.

2.3.2 Electroencephalographic Data

Subsequently, I sought to examine the effect of impulsivity and delayed rewards on the reward positivity amplitude in the delayed gratification task. A three by two mixed ANOVA was performed, and found an effect of group on reward positivity amplitude ($F(1,53) = 19.7$, $p < 0.001$, $\eta^2 = 0\ .16$); however, no effect of delay ($F(1,53) = 2.86$, $p = 0.094$, $\eta^2 = 0.03$) or group by delay interaction was found ($F(1,53) = 1.00$, $p = 0.32$, $\eta^2 = 0.01$). Given these findings, a pairwise *t*-test with the Bonferroni correction was performed and revealed that the reward positivity was larger in amplitude in individuals with low, relative to high, levels of impulsivity ($p < 0.001$, $d = 0.84$). The waveforms associated with the low and high impulsivity groups are visualized in Figures 2.32 and 2.33, respectively. Difference waveforms associated with both impulsivity groups for both reward delays are illustrated in Figure 2.34. The location, timing, and topography of the reward positivity was as anticipated for both groups (see Proudfit, 2015; Sambrook & Goslin, 2015). Topographic maps represent the amplitude and location of the difference wave for each delay condition and impulsivity level. The data also revealed that impulsivity score, as measured by the BIS-11, was negatively correlated with reward positivity amplitude for immediate ($r = -0.46$) and delayed rewards ($r = -0.25$), as well as for the overall task reward positivity ($r = -0.43$; see Appendix, table A2). Additionally, participant's reward positivity amplitudes were positively correlated between reward delays ($r = 0.37$), and immediate ($\mathrm{r} = 0.82$) and delayed rewards ($r = 0.84$) also correlated with the task reward positivity.

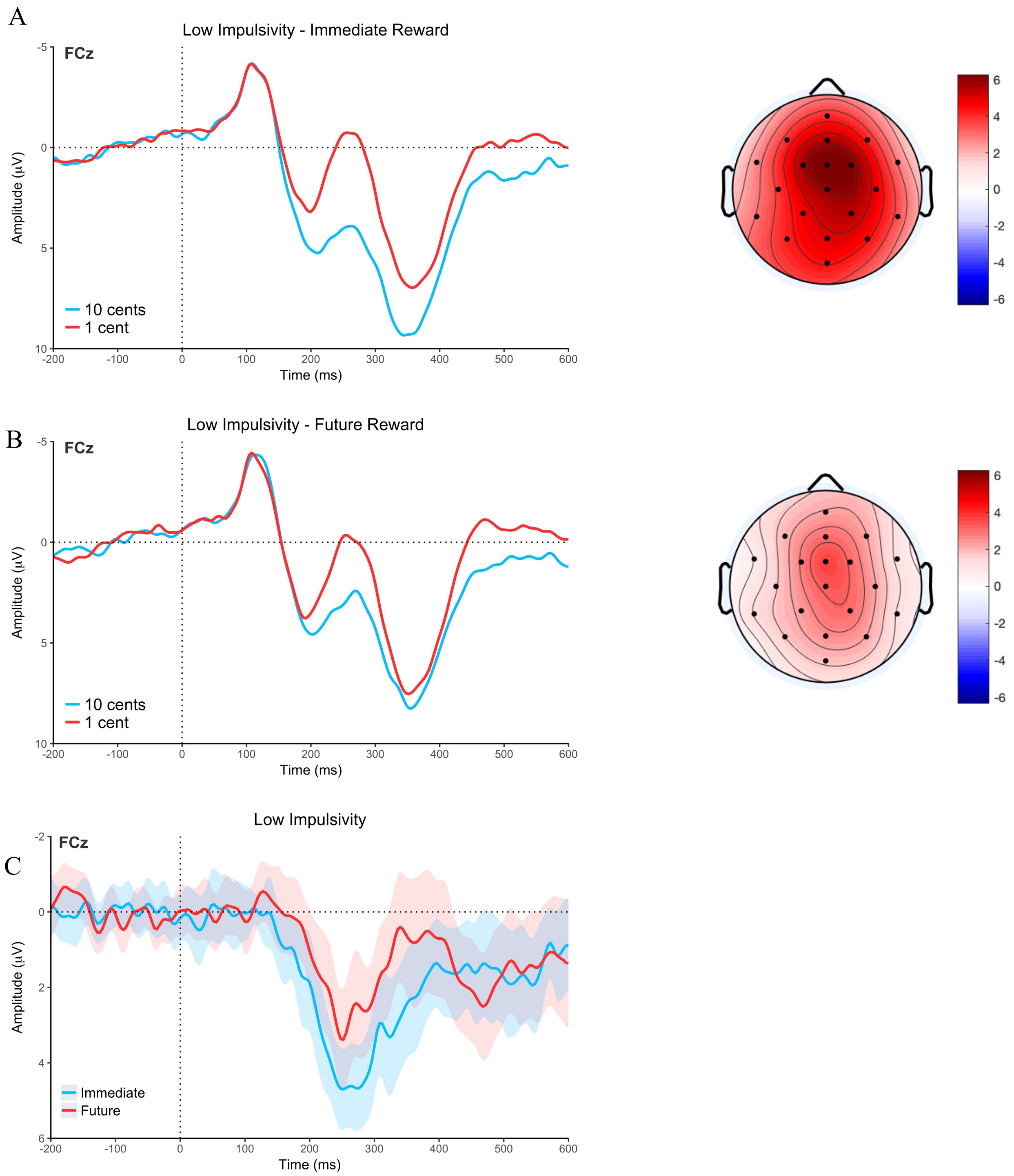


Figure 2.32. EEG waveforms for each reward magnitude (left) and topographic maps (right) for the low impulsivity group in the delayed gratification task. Topographic maps represent the location and amplitude of the associated difference wave. (A) Immediate reward, (B) future

reward, (C) conditional difference waves with 95% confidence intervals. Waveforms plotted negative up by convention.

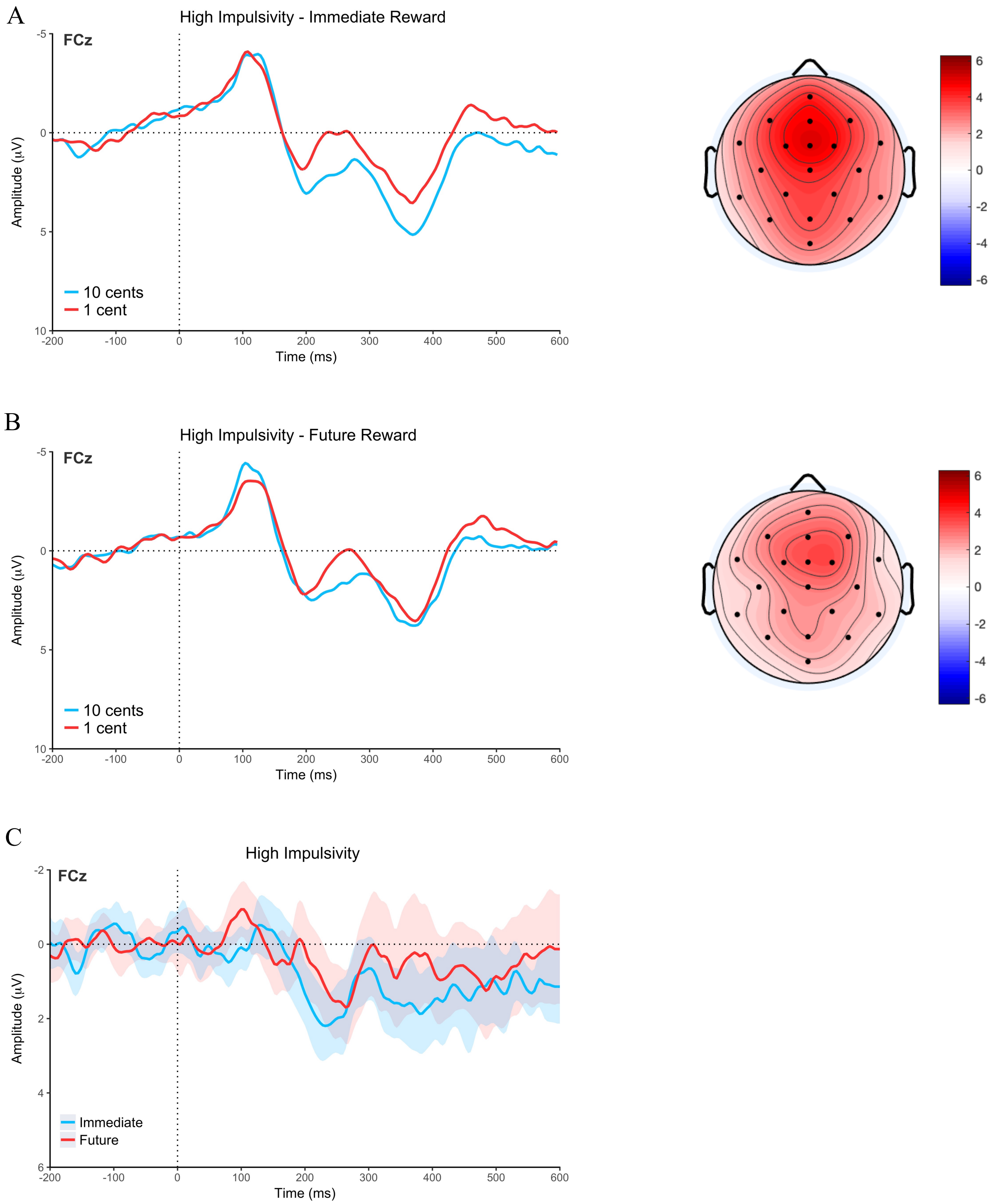


Figure 2.33. EEG waveforms for each reward magnitude (left) and topographic maps (right) for the high impulsivity group in the delayed gratification task. Topographic maps represent the location and amplitude of the associated difference wave. (A) Immediate reward, (B) future reward, (C) conditional difference waves with 95% confidence intervals. Waveforms are plotted negative up.

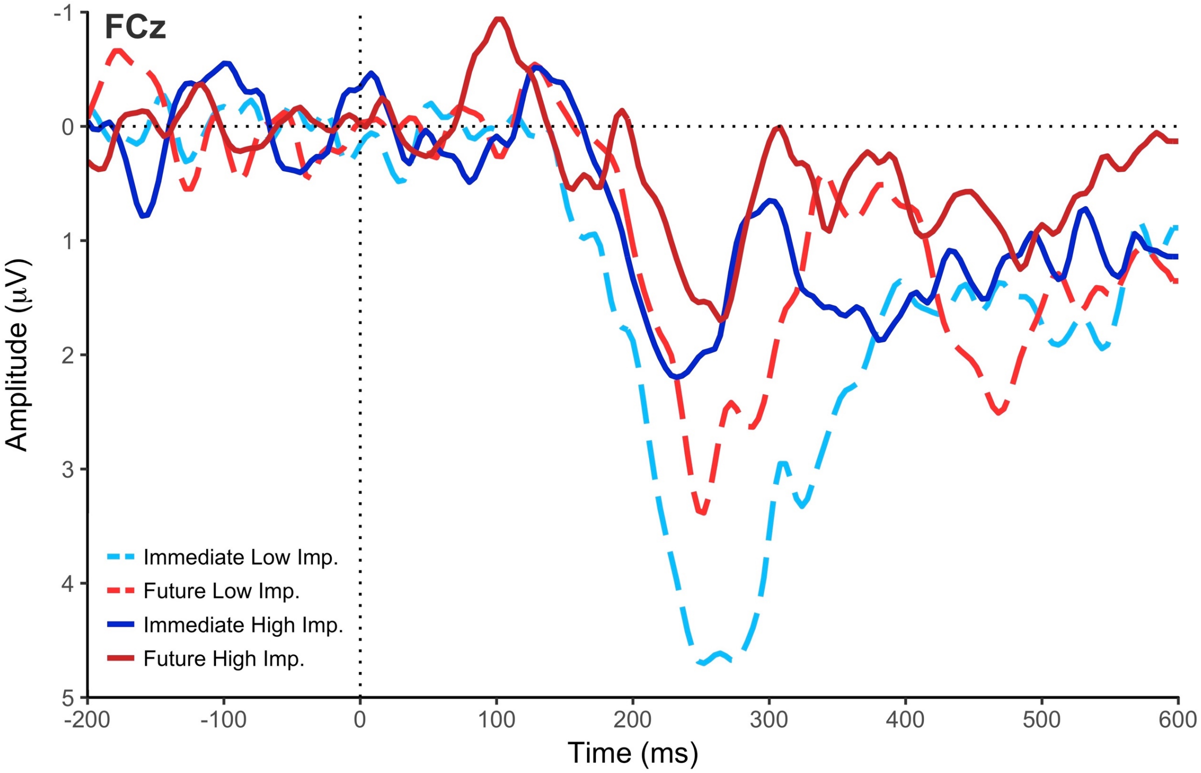


Figure 2.34. Reward positivity waveforms both high (solid) and low (dashed) impulsivity groups, for both immediate (blue) and delayed (red) rewards. Waveforms are plotted negative up by convention.

2.4 Discussion

Impulsivity is a common personality trait that has been shown to influence decision making and reward processing (Dalley & Roiser, 2012; Dalley et al., 2011). Here, I further examined those effects by investigating the role of impulsivity in the delayed gratification task. In each trial of the task, individuals received one of two rewards (i.e. 1 or 10 cents) and one of two delays (i.e. immediately or after one month). Contrary to my hypotheses, there were no response time differences between impulsivity groups in this task. I did, however, find that impulsivity modulated reward positivity amplitude, as expected.

Prior research found response time differences varied as a function of impulsivity (Gu et al., 2017; Novak et al., 2016), something that I did not find. Due to an issue with the experimental coding, I was unable to evaluate participants choice of cards and how their selection was mediated by previous reward magnitude and delay, something that has been done previously (Schmidt et al., 2017).

In line with previous research, impulsivity levels modulated the reward positivity amplitude in the delayed gratification task (Cherniawsky & Holroyd, 2013; Novak et al., 2016; B. Schmidt et al., 2017). However, my findings were in the opposite direction, where I found that the high impulsivity group had an attenuated reward positivity amplitude, when compared to the low impulsivity group. This finding supports the idea that impulsivity is associated with abnormal reward processing and dopamine levels (Pine, Shiner, Seymour, & Dolan, 2010). Importantly, my study used the BIS-11 questionnaire in order to distinguish my two impulsivity groups, while Cherniawsky and Holroyd (2013) used a delay discounting questionnaire, where the highest and lowest quartile of discounters were compared. They found that high temporal discounters (i.e. high impulsivity) individuals had a larger reward positivity to immediate, compared to delayed, rewards; moreover, despite not replicating this pattern of delay on the reward positivity, a trend in delay was observed. In the study conducted by Schmidt and colleagues (2017), a factor analysis collapsed across two questionnaires – impulsivity and self-control – was found to account for a large amount of variance in the data and was used as their impulsivity/self-control measure. Using this measure, they also found an effect of reward delay, finding that the reward positivity was larger for rewards that were immediately delivered, as compared to future rewards (Schmidt et al., 2017). Again, I observed a trend in the data in terms of delay affecting reward positivity amplitude, but failed to reach significance. This may have occurred due to the shorter duration of my temporal delay (i.e. one month), compared to previous neuroimaging studies (i.e. 6 months; Cherniawsky & Holroyd, 2013; Schmidt et al., 2017); however, Mavrogiorgou and colleagues (2017) did find an effect of delay on behavioural choice data when examining delays of two, seven, 14, 28, and 40 days.

2.4.1 Conclusion

Here I examined how impulsivity modulated reward processing and reward positivity amplitude. I found that impulsivity does influence reward processing in the delayed gratification task; however, in contrast to previous studies, I did not find an effect of reward delay. Impulsivity is a multifaceted construct that can be difficult to quantify, and it is possible that using an alternative or additional measure of impulsivity would have resulted in different effects. In the delayed gratification task, subjects were told that they would have to wait one month prior to receiving some of their rewards, a longer temporal delay may have been required to observe an effect of delay. Impulsivity is a common personality trait, but much remains unknown and many researchers have observed contradictory evidence. Future research using several measures of impulsivity and examining multiple aspects of reward processing is required to garner a more holistic understanding of the effect of impulsivity on reward processing.

Chapter 3: Time Estimation

3.1 Introduction

Individuals perceive the world around them in unique ways. Impulsivity – a personality trait associated with heightened reward sensitivity, novelty seeking, lack of premeditation, and behavioural and emotional inhibition deficits (Leshem, 2016a) – can alter the perceived value of a reward, and is it posited to result in an altered sense of time. Wittmann and Paulus (2008) propose a theory that abnormal delay discounting – the preference for small, immediate rewards, over large, future ones – is the result of an altered sense of time. Impulsivity has been shown to influence delay discounting by shifting the preference from larger future rewards to smaller immediate rewards (Dalley et al., 2011). The idea proposed by Wittmann and Paulus suggests that impulsive people overestimate the passage of time, leading them to discount rewards at a faster rate. For example, when thinking of the future impulsive people may perceive three days as seven, leading them to discount rewards at a higher than expected rate. When making a choice, the value of immediate gratification is taken into account, as well as the cost associated with waiting for a reward; additionally, when the perception of time is altered and perceived as moving too slowly, then the cost associated will also be too high. This is supported by a growing literature involving time estimation and perception tasks that require the participant to estimate when a specific duration of time has passed (e.g. how long a stimulus remained on the screen) (Berlin, Rolls, & Kischka, 2004).

When time production and perception studies were performed on impulsive individuals, adolescents were found to underproduce time intervals between one and ten seconds, which was interpreted as participants perceiving the passage of time as a slower rate (Barratt, 1981). When assessed based on their ability to match, maintain, and later produce tapping at a paced rate or tempo, impulsivity was found to correlate positively with tapping rate (Barratt et al., 1981); additionally, these researchers posit that individuals with augmented impulsivity levels also have difficulty in complex information processing (e.g. when feedback in involved), resulting in lower tapping accuracy. Time estimation and perception tasks have revealed that impulsivity is positively correlated with the overestimation of time for intervals both shorter and longer than a minute (Berlin et al., 2004; Berlin & Rolls, 2004; Corvi et al., 2012; Havik et al., 2012; Moreira et al., 2016; Schulreich et al., 2013; Wittmann et al., 2011; Wittmann & Paulus, 2008).

Little research has been conducted examining the neural correlates of time estimation. When Miltner et al. (1997) examined time estimation using electroencephalography (EEG), they found that this task elicited a reward positivity (Holroyd & Krigolson, 2007), regardless of the feedback modality (i.e. visual, auditory, somatosensory). Follow up studies adapted this task to examine the impact of reward expectancy (Holroyd & Krigolson, 2007; Williams et al., 2017).

Here, I sought to examine human reward processing and impulsivity in a new domain – the evaluation of time estimation and cognitive-motor performance. This study used time estimation, in conjunction with EEG, in order to determine the effects of impulsivity on performance and the reward positivity. Based on previous work (Berlin et al., 2004; Berlin & Rolls, 2004; Corvi et al., 2012; Havik et al., 2012; Moreira et al., 2016; Schulreich et al., 2013; Wittmann et al., 2011), I hypothesized that time estimation accuracy – as measured by window bound size – will be mediated by impulsivity. I also hypothesized that impulsivity will influence the amplitude of the reward positivity in time estimation task due to previous associations between impulsivity and decreased dopamine release (Dalley et al., 2011; Morgan et al., 2002). I therefore predicted that this task would provide new evidence into the association between the perception of time, reward processing, and impulsivity.

3.2 Method

3.2.1 Participants.

This task was also performed as part of a larger battery, as such, see section 2.2.1 for information regarding the participants.

3.2.2 Procedure and Apparatus.

See section 2.2.2 for apparatus information.

Time Estimation Task

The time estimation task required participants to estimate the duration of one second (Miltner et al., 1997). On each trial they first observed a blank screen for 50 ms, where they were presented with an auditory cue. The subjects were tasked with pressing the button one second after the auditory cue. They subsequently viewed a fixation cross for 500 to 800 ms, followed by trial feedback presented for 1000 ms. Feedback was either a "✓", representing a correct trial, or an "×", representing an incorrect trial. All stimuli in the time estimation task occupied approximately 2° of visual angle vertically horizontally. After feedback was given, a black screen was presented for 500 to 800 ms, prior to the onset of the following trial, which commenced with an auditory cue (see Figure 3.22). Participants completed 200 trials, divided into four blocks. In order to maintain approximately equal numbers of correct and incorrect trials, the parameters for correct feedback varied with performance using a stair-case procedure. After each trial the size of the time window changed. The time window decreased if the prior response occurred within the time window (i.e. win) or increased in size if the response occurred outside the time window (i.e. loss). The time window either increased or decreased in size by 30 ms each trial. This method alters the difficulty of the task, so that task difficulty is positively correlated with performance.

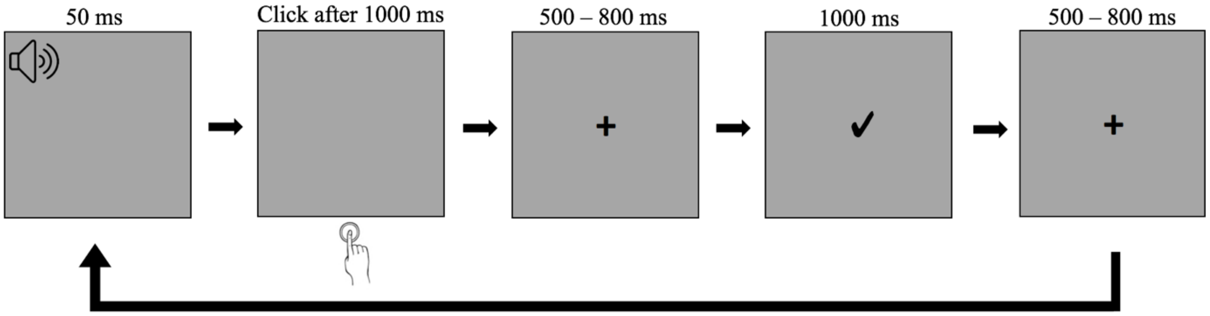


Figure 3.22. An example of one experimental trial. Participants are required to estimate the length of one second, which begins once the auditory cue is given. Once their estimation has been given, they receive feedback on their performance.

3.2.3 Data acquisition.

Accuracy (win or loss) and response time (ms) data were logged using MATLAB (Version R2017b, MathWorks Inc, Natick, USA). See section 2.2.3 for more information regarding data acquisition.

3.2.4 Data analysis.

In the time estimation task, participant's mean response times and standard deviation were calculated in order to identify outlier trials. All trials with response times four standard deviations above or below the mean were removed from subsequent behavioural and EEG analyses (mean trials removed = 4.02 [2.25, 5.79]). Each participant's behavioural data was analyzed using an independent samples *t*-test, based on the size of the average time window per impulsivity group. Effect size and 95% confidence intervals were also calculated. Following this, participants' response time changes between trials were also examined. They were divided into four conditions per impulsivity group, depending on the previous and current trial feedback (i.e. win-win, win-loss, loss-win, loss-loss). This was analyzed using three by two mixed ANOVA, with condition as a within factor and impulsivity as between. This was followed by the calculation of effect size – as measured by eta squared – which is preferable to partial eta squared for its generalizability (see Levine & Hullett, 2002). An independent samples *t*-test was then conducted to analyze the reward positivity amplitude between high and low impulsivity subjects. Subsequently, 95% confidence intervals were performed on all comparisons. Correlations between reward positivity amplitude and impulsivity score were also performed.

See section 2.2.4 for data analysis steps. This analysis differed from section 2.2.4 solely in the making of the waveforms and difference waves. Win and loss data were averaged separately for high and low impulsivity levels, to create averaged ERP waveforms. Difference waves were then created for each participant by subtracting the loss from the win waveforms between impulsivity groups. Grand average waveforms were computed for both conditional waveforms by averaging the corresponding individual waveforms.

Correlational analysis, as measured by Pearson's *r*, was also performed on the reward positivity amplitude, relating each participant's BIS-11 score to their reward positivity amplitude for the task. Additional exploratory correlations were also conducted between the reward positivity amplitude in the Time Estimation task, Delayed Gratification Task, and an average experimental reward positivity (see Appendix, table A2). This average experimental reward positivity was obtained by averaging each participant's reward positivity amplitude across tasks.

Further analysis was conducted on the difference waves for both high and low impulsivity groups, examining the P300 component. The mean P300 peak amplitude was calculated at Pz, in the same manner as the mean reward positivity peak amplitude, except that the minimum value across 200 to 600 ms post feedback was used. Single-sample *t*-tests were used to determine the presence of the P300 in both impulsivity groups, followed by an independent-samples *t*-test examining group differences in mean peak P300 amplitude.

3.3 Results

3.3.1 Behavioural Data.

I began by analyzing measures of accuracy on the time estimation task. The analysis of performance found that impulsivity level had no effect on mean window bound size. Specifically, an independent samples *t*-test found no difference between groups, $t(53) = 2.06$, $p = 0.98$. Subsequently, I sought to determine how much performance changed following win and loss trials, and if response time change was influenced by impulsivity group. A three by two mixed ANOVA with impulsivity level and feedback condition as factors indicated no effect of impulsivity group on response time change ($F(1,53) = 0.01$, $p = 0.93$, $\eta^2 = 0.00$); however, it did reveal an influence of prior and current feedback valence on response time change, ($F(3, 159) = 199.49$, $p < 0.001$, $\eta^2 = 0.52$). When both the feedback in the prior and current trials were wins, the high and low impulsivity groups had a mean response time change of 71.1 ms (CI = [61.6, 80.5] and 71.7 ms [63.4, 80.0], respectively. When a win trial was followed by a loss the mean change in response time was 170.1 ms [146.9, 193.2] for high and 170.6 ms [153.3, 187.9] for low impulsivity groups. Loss trials followed by win trials were associated with a response time change of 207.7 ms [182.7, 232.6] for high and 207.0 ms [183.2, 230.8] for low impulsivity individuals. Finally, when loss trials followed each other, highly impulsive individuals had a mean change in their response times of 197.7 ms [171.7, 223.8], while the low impulsivity group had a mean change of 192.9 [171.1, 214.8] (see Figure 3.31). No interaction was found between impulsivity group and condition ($F(3,159) = 0.01$, $p = 0.97$, $\eta^2 = 0.00$).

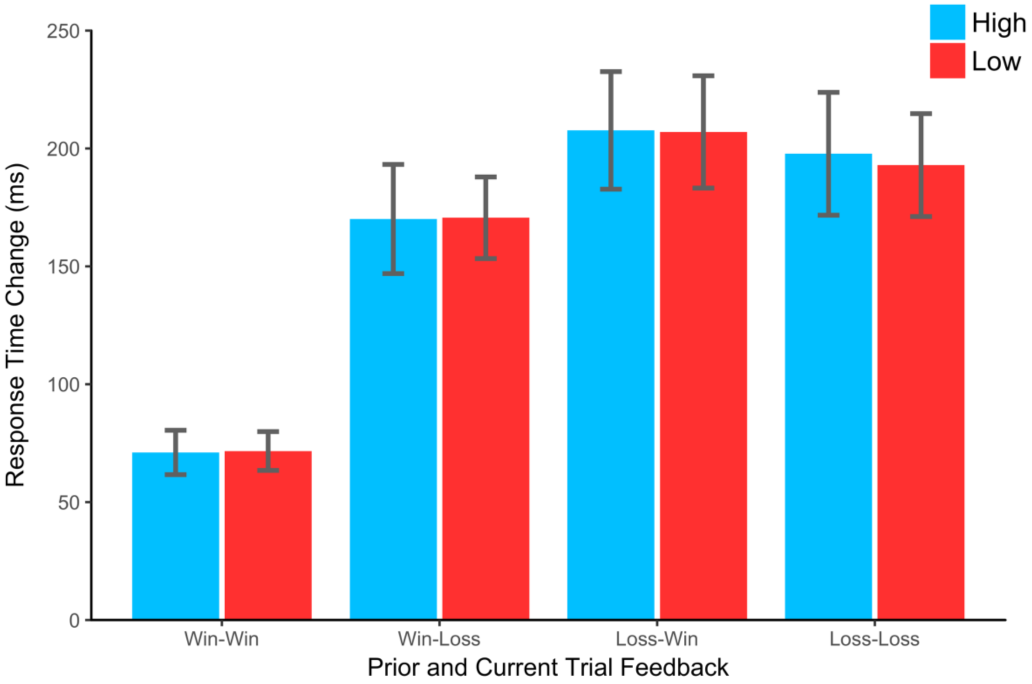
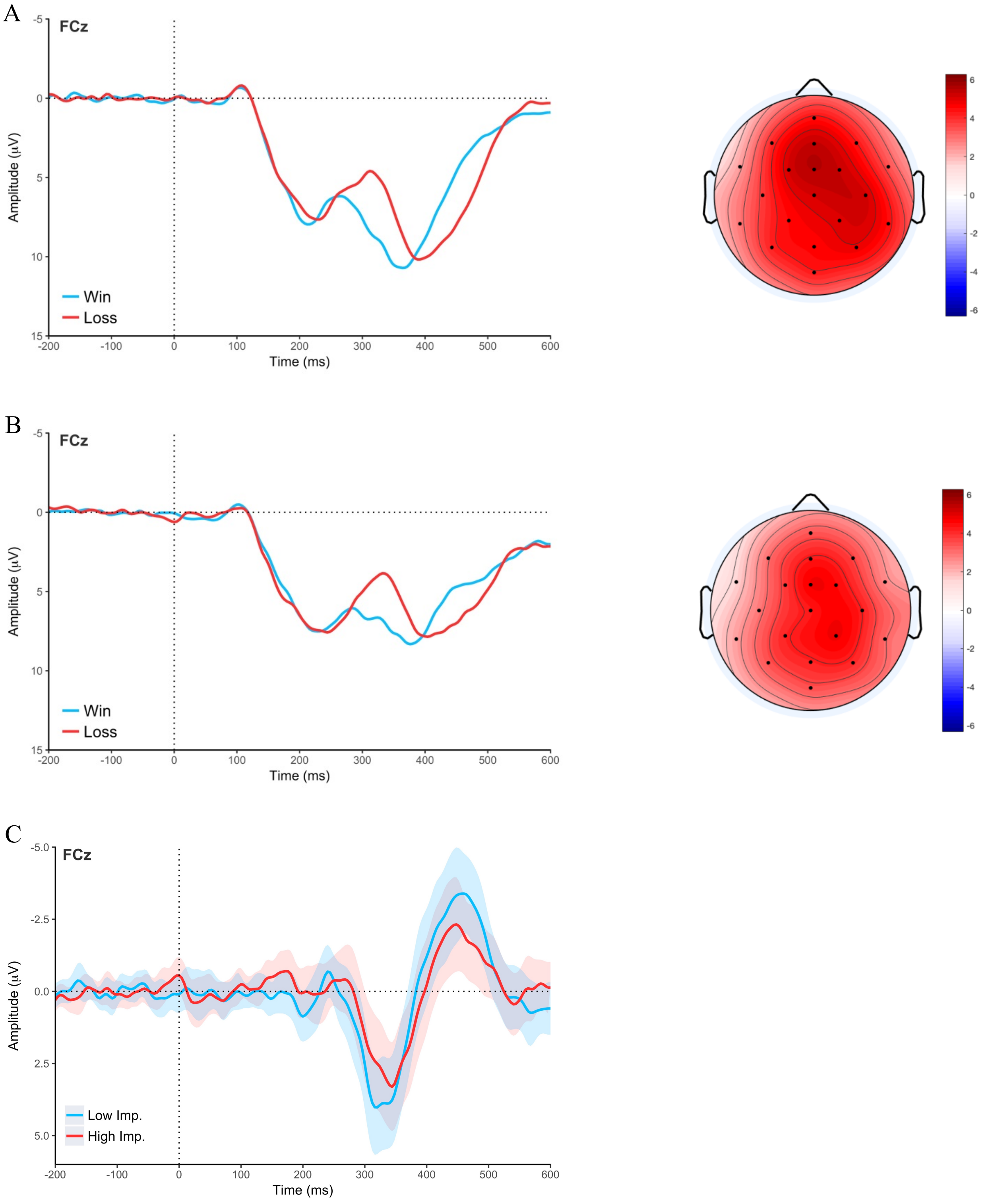


Figure 3.31. Absolute changes in response time (ms) resulting from feedback between the prior and current trial. Blue bars signify the high impulsivity group, and red bars the low group. Error bars present 95 % confidence intervals.

3.2.2 Electroencephalographic Data.

Next, I examined how impulsivity levels influenced reward positivity amplitudes in the time estimation task. This comparison was accomplished using an independent samples *t*-test, and found that the component's amplitude did not vary as a function of impulsivity level ($t(50.3) = 1.35$, $p = 0.18$, $d = 0.036$). The associated waveforms and topographic maps are presented in Figure 3.34. The location, timing, and topography of the reward positivity were as anticipated for both groups (see Proudfit, 2015; Sambrook & Goslin, 2015). Topographic maps represent the amplitude and location of the difference wave for each delay condition and impulsivity level. Further analysis of the reward positivity waveform using a single-sample *t*-test revealed the presence of the P300 component for both the low ($t(26) = 6.19$, $p < 0.001$) and high impulsivity groups ($t(27) = 4.16$, $p < 0.001$). The P300 amplitude did not change as a function of impulsivity group ($t(53) = 0.78$, $p = 0.438$, $d = 0.036$). Impulsivity, as measured by the BIS-11, was also found to negatively correlated with reward positivity amplitude ($r = -0.22$; see Appendix, table A2).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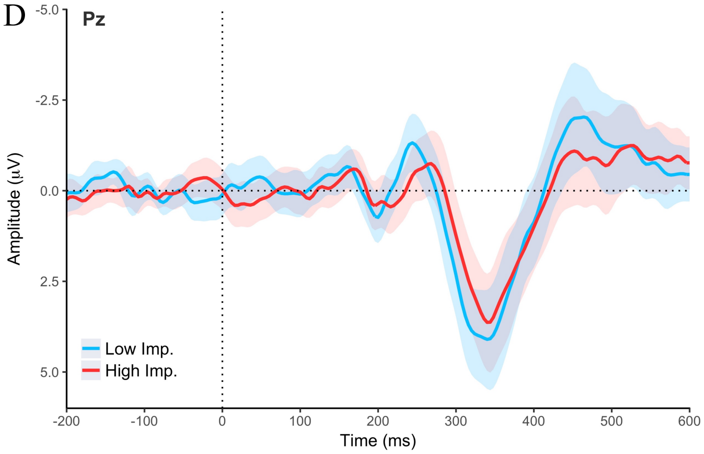

Figure 3.32. EEG waveforms for each feedback condition (left) and topographic maps (right) associated with both impulsivity groups in the time estimation task. Topographic maps represent the location and amplitude of the associated difference wave. (A) Low impulsivity group, (B) high impulsivity group, (C) group difference waves with 95% confidence intervals, (D) group difference waveform at channel Pz with 95% confidence intervals. Waveforms are plotted negative up by convention.

3.4 Discussion

Impulsivity has been associated with altered time perception, abnormal reward processing, lack of premeditation, novelty seeking, and emotional regulation deficits (Leshem, 2016a). In the current study, I explored associations between impulsivity, time estimation, and reward processing using a time estimation task. I hypothesized that implusivity would result in altered time estimation, something that I failed to find; however, I did find that prior and current trial valence had an effect on response time change between trials. I also predicted that the reward positivity amplitude would be mediated between-subjects by impulsivity level, which I also did not observe. I also found that the P300 was larger for win, relative to loss, trials, suggesting that more contextual updating was occurring following winning trials.

Prior literature suggested that impulsivity was associated with the overestimation of time (Berlin et al., 2004; Berlin & Rolls, 2004; Corvi, Juergensen, Weaver, & Demaree, 2012; Havik et al., 2012; Moreira, Pinto, Almeida, & Barbosa, 2016; Schulreich, Pfabigan, Derntl, & Sailer, 2013; Wittmann et al., 2011). However, I did not replicate this, as the time window bounds did not differ as a function of impulsivity. Contrary to other paradigms, I maintained an equal accuracy rate between participants – due to the changing window size – which allows my participants to have an equal number of win and loss trials. When examining the absolute behavioural change after win and loss trials, my findings were in accordance with Holroyd and Krigolson (2007), who also found that participants altered their response times more following a loss than following a win trial.

Research has shown that impulsivity is associated with abnormal reward processing and decreased levels of dopamine (Dalley & Roiser, 2012), leading us to predict a difference in reward positivity amplitudes between levels of impulsivity, a result that I failed to find. Instead, I found no difference between the mean peak reward positivity amplitudes in the high and low impulsivity groups; although, there was a trend in amplitude in the predicted direction. This finding suggests that impulsivity does not always affect reward processing in an obligatory manner. A reason for this may have been the short interval that was estimated, and others have estimated much longer durations, even into the range of several minutes.

3.4.1. Conclusion

Here I examined how impulsivity modulated reward processing, time estimation, and the reward positivity amplitude. I found that impulsivity does not influence reward processing in the context of time estimation. Impulsivity is a multifaceted construct that can be difficult to quantify, and it is possible that using an alternative or additional measure of impulsivity would have resulted in different effects. The paradigm also controls for performance due to the use of EEG, but this is something that previous behaviour studies did not do. Impulsivity is a common personality trait, but much remains unknown and many researchers have observed contradictory evidence. As this is the first study of its kind to examine impulsivity and time estimation in conjunction with EEG, future research using several measures of impulsivity and examining multiple different types of timing and time intervals is required to uncover the neural correlates of impulsivity and time estimation.

Chapter 4: General Discussion

Impulsivity is a common personality trait that has been shown to influence decision making and reward processing (Dalley & Roiser, 2012; Dalley et al., 2011). Here, I reviewed literature examining the behavioural, neurochemical, and anatomical features of impulsivity, as well as common neurological and psychological disorders associated with it. Using the delayed gratification and time estimation tasks, I further explored the role of impulsivity in reward processing, as well as the passage of time. Contrary to my hypothesis, there were no response time differences between impulsivity groups in the delayed gratification task, nor were there differences in mean window bound size in the time estimation task. Further inspection into response time changes in the time estimation task revealed an effect of prior and current trial valence within each impulsivity group, with no group differences apparent. In accordance with my predictions, the reward positivity amplitude was modulated by impulsivity level in the delayed gratification task; however, contrary to expectations, no difference in reward positivity amplitude was found in the time estimation task.

4.1 Behaviour

Previous work suggested that impulsivity was associated with the overestimation of time (Berlin et al., 2004; Berlin & Rolls, 2004; Corvi, Juergensen, Weaver, & Demaree, 2012; Havik et al., 2012; Moreira, Pinto, Almeida, & Barbosa, 2016; Schulreich, Pfabigan, Derntl, & Sailer, 2013; Wittmann et al., 2011), which I did not replicate, as the time window bounds did not differ as a function of impulsivity. My findings also contradicted the theory proposed by Wittmann and Paulus (2008), who posited that impulsive individuals overestimate the passage of time due to abnormal time perception, leading them to discount rewards at a higher rate. My inability to replicate abnormal time estimation may have been due to a short estimation interval, or importantly, the immediate and frequent feedback given in the time estimation task. This feedback may have allowed for better learning and performance correction than other studies. Additionally, the paradigm maintains an equal accuracy rate between participants – due to its changing window size – which allowed my participants to have an equal number of win and loss trials.

When examining the absolute behavioural change after win and loss trials, my findings were in accordance with Holroyd and Krigolson (2007), who also found that participants altered their response times more following a loss, than a win, trial. This was done in an attempt to improve performance following loss trials, and replicate performance following win trials.

4.2 Reward Positivity

In accordance with previous findings I found that impulsivity levels influenced the reward positivity amplitude in the delayed gratification task (see Table 1; Cherniawsky & Holroyd, 2013; Schmidt et al., 2017). I found that the high impulsivity group had an attenuated reward positivity amplitude, when compared to the low impulsivity group; additionally, this supports the idea that impulsivity is associated with abnormal reward processing and dopamine levels (Pine et al., 2010). Many researchers have found an effect of reward delay (Cherniawsky & Holroyd, 2013; Schmidt et al., 2017), a finding that I failed to replicate; however, there was a trend in the reward positivity amplitude in the predicted direction. This may have occurred due to the shorter duration of the temporal delay used (i.e. one month), compared to previous studies (i.e. 6 months; Cherniawsky & Holroyd, 2013; Schmidt et al., 2017).

Table 1.

Methods, assessment, and findings of impulsivity's effect on reward positivity amplitude from previous delayed gratification/discounting studies.

Study	*N*	Impulsivity Assessment	EEG Task	Reward Positivity Results
Cherniawsky & Holroyd (2013)	40	Written intertemporal decision-making task	T-maze involving randomly delivered 25¢ or 1¢ rewards, either immediately or after a 6-month delay per trial	High discounters in the written assessment had larger reward positivities to immediate rewards
Gu et al. (2017)	86	Impulsive Sensation Seeking Scale from the Zuckerman-Kuhlman Personality Questionnaire	Monetary incentive delay task, wherein participants would win or lose either $1.20, 12¢, or 0¢ depending on performance per trial	Impulsivity was associated with a larger reward positivity in the neutral reward condition
Huang et al. (2017)	37	Computer-based intertemporal decision-making task	Valuation task were participants chose between 2 images and either won or lost $1.50 immediately, or after a month, in each trial	Adolescents were more impulsive and had decreased reward positivity amplitudes, compared to adults, for delayed rewards.
Novak et al. (2016)	92	Urgency, Premeditation, Perseverance, and Sensation Seeking (UPPS) Impulsive Behaviour Scale	Monetary incentive delay task where participants received 20¢ or lost 10¢ depending on their performance (i.e. if they made their response while the stimuli was on the screen).	Lack of premeditation was associated with a decreased reward positivity
Schmidt et al. (2017)	20	UPPS Impulsive Behaviour Scale, Self-Control Scale	Delayed gratification task, wherein participants selected 1 of 4 cards, rewards of 1¢ or 10¢ immediately or after 6-months, were randomly given	High impulsivity and low self-control was associated with a larger reward positivity to immediate, than delayed, rewards.

Time estimation and perception research has shown that impulsivity is associated with abnormal reward processing and decreased levels of dopamine (Dalley & Roiser, 2012), leading us to predict a difference in reward positivity amplitudes between levels of impulsivity, a result that I was unable to find. Instead, I found no difference between reward positivity amplitudes in the high and low impulsivity groups. This finding suggests that time estimation and delay discounting are examining different facets of reward processing.

4.3 New Perspective

In light of the idea that these two different reward processing tasks are examining distinct underlying processes, four additional ERP plots were made (see Figures 4.31 and 4.32). The plots in Figure 4.31 present the average reward positivity per impulsivity group per task; additionally, the plots in Figure 4.32 represent the averaged waveform for each task, averaged across impulsivity level (and delay in the delay discounting task). Visual examination of Figure 4.31 shows that there appears to be reward positivity difference between the tasks for the high impulsivity group; furthermore, there is a large negative peak following the reward positivity in the time estimation task, which is absent in the delayed gratification task. A visual inspection of Figure 4.32 reveals large differences between the waveforms, not only are the waveforms larger in magnitude in the time estimation task (i.e. right plot), but the delayed gratification waveform (i.e. left plot) also had a large N1 component. Visual inspection of both Figures 4.31 and 4.32 clearly show a difference in average waveforms between these two tasks, something that cannot be explained by task order, as these tasks were performed in a counterbalanced order as part of a larger battery. One influence could be the effect of monetary reward, present in the delay discounting, but not the time estimation task. The use of real monetary reward may have involved the recruitment of other brain regions and lead to more impulsive behaviour. Previous research has shown that the use of real versus hypothetical money influences behaviour and the differential activation of neural regions (Fantino, Gaitan, Kennelly, & Stolarz-Fantino, 2007; Hinvest & Anderson, 2010; Kang, Rangel, Camus, & Camerer, 2011; Wilbertz et al., 2012; Xu et al., 2016); however, these comparisons were made within the same task. The differential valuation of rewards has also been observed in atypical populations. A study examining how money and cigarettes are valued by smokers found that smokers had a larger reward positivity amplitude to cigarettes than money, when compared to non-dependent smokers (Baker, Wood, &

Holroyd, 2016). This shows that cigarettes were more highly valued than money, for cigarette dependent smokers. Interestingly, children with attention deficit hyperactivity disorder were found to have larger reward positivity amplitudes to monetary rewards, than to points, a pattern that was not observed in control subjects (Umemoto, Lukie, Kerns, Müller, & Holroyd, 2014). Taken together, these studies provide evidence that different reward stimuli can have a differential effect on reward processing in both typical and atypical populations.

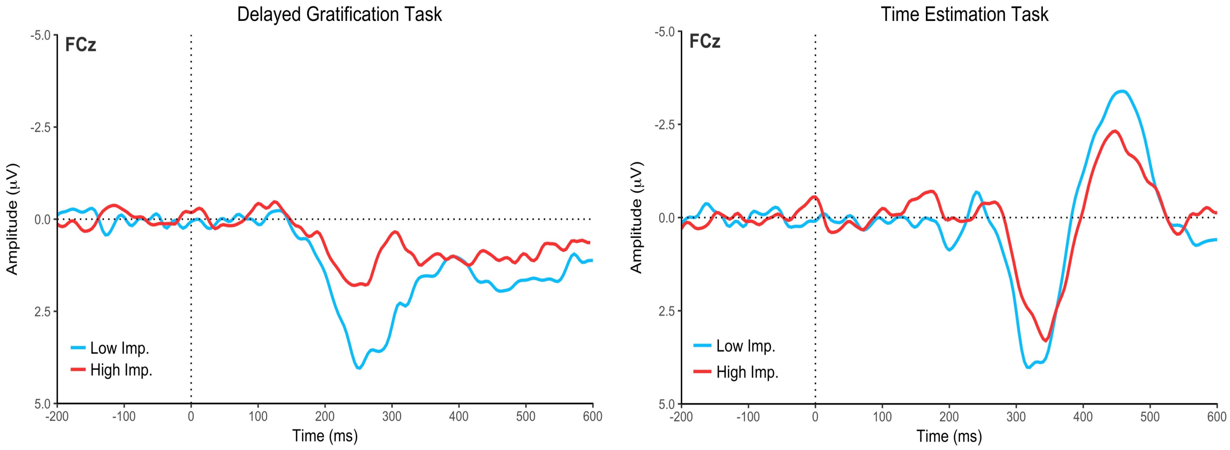

Figure 4.31. Average reward positivity waveforms between impulsivity groups in the Delayed Gratification (left) and Time Estimation (right) tasks. Waveforms are plotted with negative up, by convention.

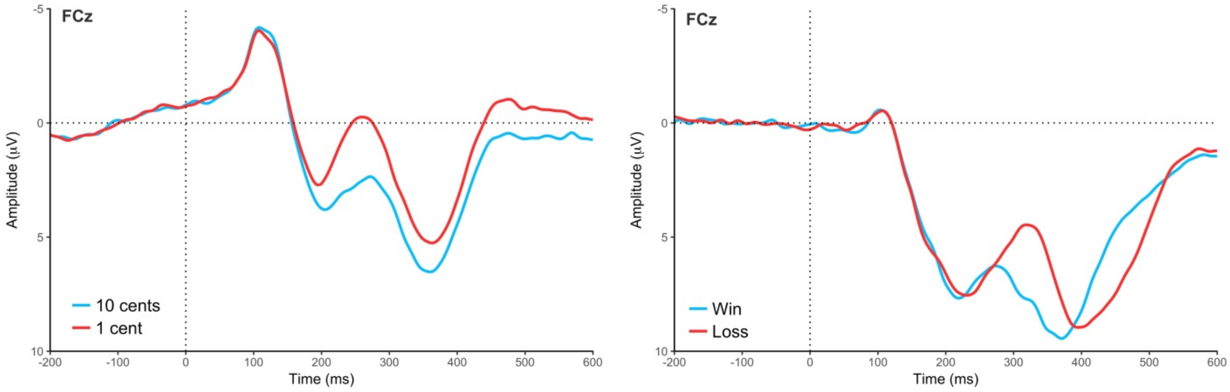

Figure 4.32. Averaged waveforms across impulsivity group and reward delay in the Delayed Gratification (left) and Time Estimation (right) tasks. Waveform is plotted with negative up, as by convention.

My results demonstrate that impulsivity is associated with reward processing abnormalities, but not under all circumstances. Furthermore, during the delayed gratification – but not time estimation – task, participants were informed that they would receive money based on their performance during the task. Since I observed a difference in reward positivity amplitudes in one of the tasks and not the other, I suggest that money may provide a larger motivational influence on individuals with high impulsivity, than low impulsivity; moreover, this added motivation leads them to act more impulsively. This may explain the observed discrepancies in reward positivity amplitudes between tasks.

Another explanation for the finding that impulsivity influenced the reward positivity amplitude in the delayed gratification, but not time estimation, task is cognitive load. Previous research examining the effect of cognitive load on conditional waveforms and the reward positivity found that high levels of cognitive load were associated with a decreased reward positivity amplitude (Krigolson, Hassall, Satel, & Klein, 2015; Krigolson, Heinekey, Kent, & Handy, 2012). Importantly, these same studies also found no behavioural differences as a function of cognitive load, supporting my findings where no behavioural differences were found between impulsivity groups for each task. An additional study, conducted by Cockburn and Holroyd (2018), found that the complexity of feedback stimuli was negatively associated with reward positivity amplitude. One potential explanation given by the authors suggest that more complex stimuli could result in decreased motivation during the task. Attentional and motivational deficits have been associated with impulsivity and could explain the decreased reward positivity in the delayed gratification task. Taken together, the studies conducted by Cockburn and Holroyd (2018) and Krigolson et al. (2015, 2012) suggest that stimuli complexity may contribute to the amplitude differences observed in the conditional and reward positivity waveforms between tasks.

Importantly, my results change depending on the statistical values relied on: *p*-value, effect size, or correlations. Depending on which tests were used, my findings support or contradict previous findings. Further investigation into the association between impulsivity and reward positivity amplitude revealed an effect of impulsivity on the reward positivity for the delayed gratification, but not the time estimation, task (see Appendix, Table A1). Furthermore, a weak effect was found between immediate and delayed rewards, as well as between delays in the low impulsivity group for reward positivity amplitude. A moderate effect was present for future rewards between impulsivity groups. A large effect was observed between impulsivity groups and between immediate reward and impulsivity group in terms of the reward positivity. Importantly, when assessing significance based on *p*-values alone, the only significant finding was the difference in reward positivity amplitude between impulsivity levels. Interestingly, impulsivity had a weak negative correlation with reward positivity amplitude in the time estimation task and was moderately correlated with reward positivity amplitude in the delay gratification task (see Appendix, Table A2). This lends support to the idea that impulsivity influences reward processing and the reward positivity.

4.4 Limitations & Future Research

Impulsivity is a multifaceted construct that can be difficult to quantify, and it is possible that using an alternative or additional measure of impulsivity and/or monetary reward would have resulted in different effects. In the delayed gratification task, subjects were told that they would have to wait one month prior to receiving some of their rewards; however, a longer temporal delay may have been required to observe an effect of delay. Additionally, despite being informed on multiple occasions that the participants will receive the monetary reward displayed on the screen, many subjects revealed during the debrief that they believed they were being deceived and would not be granted their monetary reward. My findings rely on the type of statistics used, and whether the presence of an effect relies solely on the *p*-value, or if the effect size is taken into account. As stated above, some of my findings are supported by the effect sizes calculated, while some are not. Impulsivity is a common personality trait, but there is a large volume of contradictory evidence surrounding some aspects, and no literature surrounding others. Future research using several measures of impulsivity and examining multiple aspects of reward processing is required to garner a more holistic understanding of the effect of impulsivity on reward processing. An additional study examining other neural correlates, aside from the reward positivity, is also required.

4.5 Conclusion

This paper examined the effect of impulsivity on decision making and reward processing. My findings suggest that impulsivity does influence reward processing, but that the reward tasks used are examining different underlying processes. I also observed typical time estimation and response times in individuals with high levels of impulsivity. Importantly, my findings vary depending on the type of statistics performed, which large effect sizes being found, despite a lack of statistical significance. In light of these findings, further experimentation should use several measures of impulsivity and multiple tasks to better assess reward processing.

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Appendix

Table A1.

Effect size – measured by Cohen's d – and p-values between reward positivity amplitudes, impulsivity group (i.e. high and low), and reward timing (i.e. immediate and future).

	Delay Gratification Task						Time Estimation Task
	Immediate x future reward	Immediate reward x group	Future reward x group	High x low impulsivity	Low impulsivity x reward time	High impulsivity x reward time	High x low impulsivity
d	0.29	1.13	0.61	0.84*	0.48	0.14	0.036

* $p < 0.05$

Table A2.

The correlational matrix (Pearson's r) between impulsivity scores – measured by BIS-11 Scores – and reward positivity amplitudes per task, as well as an averaged experimental reward positivity. P-values also shown.

	1	2	3	4	5	6
1. BIS-11 Score	-					
2. Delay Gratification Task – Immediate Reward	-0.46	-				
3. Delay Gratification Task – Future Reward	-0.25	0.37	-			
4. Average Delay Gratification Task	-0.43	0.82	0.84	-		
5. Time Estimation Task	-0.22	0.22	-0.01*	0.12*	-	
6. Experimental Reward Positivity	-0.40	0.61	0.45*	0.64*	0.84*	-

* $p < 0.05$