Exploring the relationship between confidence and Gray's Reinforcement Sensitivity Theory

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Abstract

Studies have shown that Behavioural Inhibition and Behavioural Activation Systems map onto an individual's personality traits and are sensitive to punishment and reward. Further, studies of punishment and reward have been linked to dopamine pathways in the Basal Ganglia. However, these models have been criticised for being overly simplistic and rooted in animal experimentation. Consequently, little is known about the influence on meta-cognitive processes, such as confidence judgments, on personality and reinforcement learning in humans. By pairing a Go / No-Go reinforcement learning task, used to measure learning from positive and negative feedback, with a confidence rating scale to assess metacognition and comparing these results to self-report measures of reward and punishment sensitivity we hoped to uncover a link between personality and confidence in reinforcement learning. Using multiple linear regression our research found that there is a link between sensitivity to reward and confidence in learning from positive feedback, but no link was found between confidence and sensitivity to punishment. The contribution of metacognition is generally ignored but our results show that it plays an important role in sensitivity to reward which has implication for disorders that involve the Basal Ganglia such as substance abuse.

Keywords: [BIS/BAS, Basal Ganglia, Confidence, Reinforcement Sensitivity Theory]

Declaration

This thesis contains no material which has been accepted for the award of any other degree or diploma in any University, and, to the best of my knowledge, this thesis contains no material previously published except where due reference is made.

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October 2019

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Chapter 1: Introduction

1.1 Overview

The awareness and understanding of our thought processes plays a crucial role in our decision making, as we try to accurately predict the consequences of our actions in order to maximise rewards and avoid punishments. A human's adaptation to their environment has always relied on their ability to learn from reward and punishment, with the brain continuously making predictions and comparing outcomes, thereby learning about the setting they find themselves in (Fiorillo, Tobler & Schultz, 2003). Analysing how people learn in relation to reward and punishment can have profound implications for neurological disorders such as Parkinson's Disease as well as the psychological maladies of substance abuse, eating disorders, and psychopathology (Frank, Seeberger & O'Reilly, 2004; Harrison, Treasure & Smillie, 2011; Goodwin, Browne, Rockloff & Loxton, 2016; Jonason & Jackson, 2016). Furthermore, it has been argued that the study of the general laws of behaviour are inextricably related to personality (Gray 1983, p. 32).

Gray's psychophysiological theory of personality, Reinforcement Sensitivity Theory (RST), posits that conceptual neuropsychological systems underlie individual differences through sensitivity to punishment and reward (Gray & McNaughton, 2000). Gray proposed that the Behavioural Activation System (BAS) is sensitive to appetitive stimuli, it functions to initiate exploratory and approach behaviours that bring people closer to rewarding reinforcers. In contrast, the Behavioural Inhibition System (BIS) is sensitive to aversive stimuli, its purpose is to suppress behaviour that is expected to lead to punishment (Corr, Pickering & Gray, 1995). Despite its appeal, evidence that learning about rewards and punishment is related to these personality traits is mixed, with Gray's theory having undergone extensive elaboration and revision over the last 30 years (Corr, 2004). Although so far overlooked, confidence in one's ability to learn through reinforcement could play an important role in the continued elaboration of RST and may explain why the evidence in favour of this theory is mixed.

Confidence can be defined as a feeling of validity that arises from constructed accuracy judgements about the world and the initiated course of actions that accompany them (Jackson, Kleitman, Stankov & Howie, 2017). It is a task specific metacognitive experience (Efklides, 2011), that is trait like in nature (Stankov, Kleitman & Jackson, 2015). Confidence is the indispensable monitoring component needed to initiate an action in the decision-making process (Jackson, et. al., 2017), which makes it a likely contributor to the BIS and BAS and may explain these personality characteristics above and beyond the ability to learn about reward and punishment.

Consequently, this study aims to investigate the relationship between confidence and the behavioural mechanisms and personality dimensions that are governed by sensitivity to reward and punishment. Although confidence has been implicated in numerous cognitive abilities (Stankov & Crawford, 1996, 1997; Pallier et.al., 2002; Jackson, Kleitman, Howie & Stankov, 2016), previous research examining the relationship between overall confidence and Reinforcement Sensitivity Theory is relatively rare and characterised by inconsistent findings. Our main objective is to explore whether sensitivity to punishment and reward could be predicted from confidence in one's learning from these sensitivities, which could provide directions to further develop theories of personality based on reinforcement learning.

1.2 Biological Theories of Personality.

There are several theories of personality that have their basis in the neurobiological systems of the brain. The neurobiology of complex traits and behaviours is not well understood, however, research into this area has been conducted by eminent psychologists such as Ivan Pavlov, Hans Eysenck and Jeffrey Gray, with each successive theoretician adding to the model of their predecessor (Figure 1).

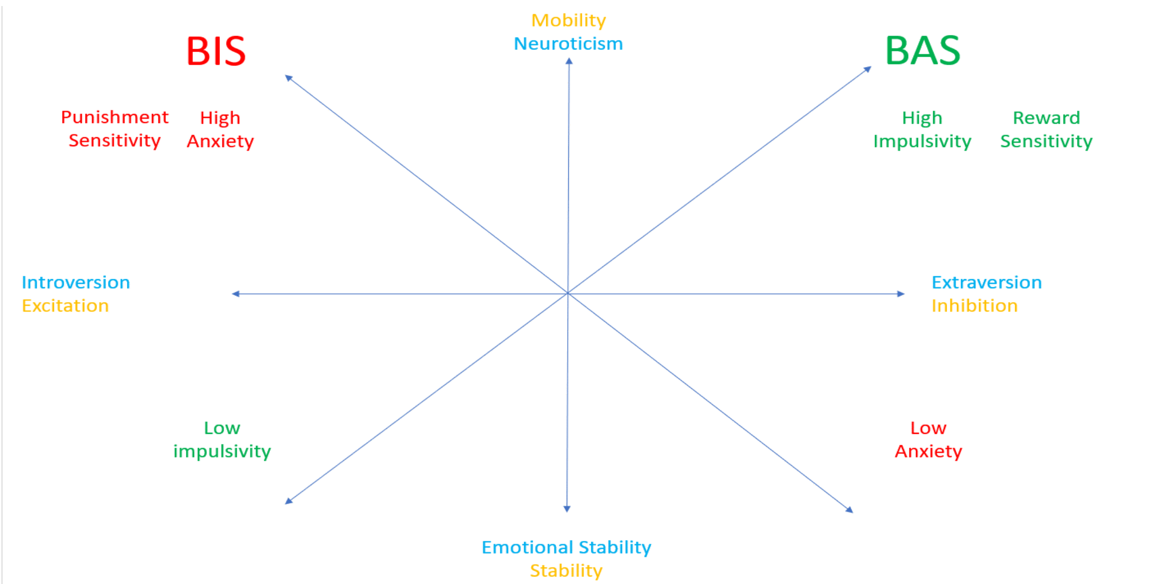

Figure 1. Biological Theories of Personality. In orange are Pavlov's personality dimensions. In Blue are Eysenck's personality traits. In Red and Green are Gray's conceptual nervous systems of the BIS and BAS which are thought to cause the personality traits of Anxiety and Impulsivity and are modulated by an individual's Sensitivity to Punishment and Sensitivity to Reward. In this diagram the BIS and BAS systems are orthogonal to the personality traits of Neuroticism and Extraversion, however, in the revised reversion of Gray's Reinforcement Sensitivity Theory, the BIS and the BAS are rotated to 30º and not the 45º shown in the above diagram. This is because the BAS appears to lie closer to Extraversion than Neuroticism.

1.2.1 Ivan Pavlov – strength of central nervous system. Psychophysiological theories of learning and personality were first proposed by Ivan Pavlov (Pickering, 1997; Pavlov, 1927). Pavlov's work on the conditioned reflex was seminal to modern understanding of associative and reinforcement learning, however, he also theorized a three-dimensional model of personality rooted in the Central Nervous System, which involves the dimensions of strength of excitatory processes, the equilibrium between excitation and inhibition, and mobility, which is the ability of the nervous system to give one impulse (either excitation or inhibition) priority over the other. He proposed that response thresholds in individuals were subject to varying stimulus intensities, with "weak" nervous systems being characterized by low response thresholds and "strong" nervous systems by higher thresholds. However, this view is considered too simplistic a representation of human personality, as it was derived from animal experimentation (Pickering, 1997).

1.2.2 Hans Eysenck – arousal of central nervous system. Following Pavlov, Hans Eysenck began his work in personality with the investigation of the statistical structure of medical symptoms observed in war veterans from the Second World War who had presented with combat stress reactions, the precursor to Post-Traumatic Stress Disorder (Corr & Perkins, 2006). Through factor analysis, he isolated two major dimensions which he conceptualized as Extraversion and Neuroticism based on their correlation with the psychological disorders of dysthymia and hysteria (Eysenck, 1944, 1947). In 1957 he published a causal theory of personality, aligning Pavlov's concepts of excitation–inhibition with introversion–extraversion and mobility with neuroticism (Corr & Perkins, 2006). This theory was reformulated in 1967 in modern terms with extraversion being linked to cortical arousal, and limbic activation to neuroticism (Eysenck, 1967).

1.2.3 Jeffrey Gray – Reinforcement Sensitivity Theory. In contrast to Pavlov's theory of strength or Eysenck's theory of arousability, Gray's Reinforcement Sensitivity Theory (1970,1972,1981,1982,1987) emphasizes an individual's sensitivity to reward (SR) and their sensitivity to punishment (SP). Research has shown that people with high degrees of introversion express a high SP as introversion involves a heightened susceptibility to fear which results in strong tendencies towards passive avoidance and extinction of once rewarded behaviour (Gray, 1970). SP is more behavioural and cognitive in nature than it is somatic (Torrubia, Avila, Molto, & Caseras, 2001). Research has demonstrated that the SR construct is harder to define as different punishments can produce homogenous effects whereas rewards take on different characteristics depending on the individual, which would produce less consistency for reward reactions, consequently, factor analysis has shown that the SR has been positively correlated with both Extraversion and Neuroticism (Torrubia, et.al., 2001).

The sensitivities to reward and punishment are the substrates of two independent behavioural systems that give rise to two personality dimensions (Pickering, 1997). Reinforcement Sensitivity Theory posits that Anxiety is caused by a person's sensitivity to punishment and is produced in the Behavioural Inhibition System (BIS) (Corr & Perkins, 2006). In contrast, Impulsivity is caused by a person's sensitivity to reward and is generated by the Behavioural Activation System (BAS) (Corr & Perkins, 2006). The most straightforward prediction from Reinforcement Sensitivity Theory is that, without salient reinforcement cues, the largest change in BAS-mediated behavior in a reward condition will be found for subjects with high scores on BAS-related personality traits (Pickering, 1997). Similarly, the largest change in BIS-mediated behavior in a punishment condition is predicted for subjects with high scores on BIS-related personality traits (Pickering, 1997).

1.2.3.1 The behavioural inhibition system. The purpose of the BIS is to suppress behaviour that is expected to lead to punishment. This inhibition is a form of controlled processing in which any ongoing behaviour is temporarily interrupted, so that delays in responding can give more time for processing the environment accurately and making fewer errors (Pickering, 1997). Being sensitive to punishment, the BIS increases levels of arousal and attention (Corr, Pickering & Gray, 1994).

Studies show that introverts have superior avoidance behaviours due to over-arousal, making them more susceptible to fear (Gray, 1983). Further research has indicated that a mixture of neuroticism and introversion with components of risk aversion make up the anxiety dimension (Torrubia, et.al., 2001).

1.2.3.2 Anxiety. Anxiety can be defined by the emotional states of punishment, frustrative non-reward, novel and innately fear-provoking stimuli (Pickering, 1997). Research has demonstrated that neurotic – introverts display highly anxious behaviours (Leue & Beauducel, 2016). Reinforcement Sensitivity Theory posits that anxiety results from conflicts between competing goals, namely, between approach or avoidance goals (Corr & Perkins, 2006). Consequently, the BIS has been characterized as the neuropsychological epicenter of anxiety (Smillie, Pickering & Jackson, 2006). Meta-analytic review has confirmed the connection between high anxiety and BIS reactivity (Leue & Beauducel, 2016).

1.2.3.3 The behavioural activation system. The BAS is sensitive to appetitive stimuli and is associated with high extraversion and neuroticism (Corr, Pickering & Gray, 1994). Being sensitive to reward, and the omission or termination of punishment, the BAS functions to initiate exploratory and approach behaviours that bring people closer to positive reinforcers (Corr, Pickering & Gray, 1994). In Gray and McNaughton's (2000) revised model, the BAS still functions as a reward system, however, in contrast with the original version of Reinforcement Sensitivity Theory, it is now thought to mediate responses to all appetitive stimuli. Further, it is proposed to be the causal basis for the Impulsivity personality dimension (Corr, Pickering & Gray, 1994)

1.2.3.4 Impulsivity. Impulsivity is reflected in the sensitivity of the BAS to classically conditioned stimuli that predict reward or relief from punishment (Pickering, 1997). Torrubia et. al. (2001) confirmed through factor analytic studies that Impulsivity is a multifactorial concept that has also been found to correlate positively with extraversion and neuroticism, furthermore, when measured using criteria that relate to sensitivity to reward is located closer to Extraversion than Neuroticism.

Impulsivity can be described as the dimension running from stable introverts, at the low end, to neurotic extraverts, at the high end, with a tendency to act quickly without deliberating. High correlations have been found between impulsivity and other traits such as sensation seeking, and antisocial tendencies (Pickering & Gray, 2001).

1.2.3.5 Sensitivity to reward and punishment. The personality dimensions of impulsivity and anxiety are thought to be caused by an individual's sensitivity to reward and punishment (Corr & Perkins, 2006). These sensitivities are representative of the conceptual nervous systems of the BIS and BAS. These conceptual systems have been mapped onto neurophysiological systems that are governed by the neurotransmitter dopamine, in particular the Basal Ganglia, a set of midbrain nuclei involved in learning from rewards and punishment (Smillie, 2008).

1.3 Biological Pathways Thought to Underlie the BIS and BAS

1.3.1 The Basal Ganglia. The conceptual personality systems of the BIS and BAS are thought to rely on dopamine-sensitive pathways in the Basal Ganglia. The Basal Ganglia act like a gate between the motor cortex, that initiates motor commands, and the thalamus, which allows the motor plan to be performed, via two dopamine-activated pathways which act to select or inhibit motor commands (Frank, Samanta, Moustafa, & Sherman, 2007). The two pathways within the basal ganglia either strengthen or weaken the tonic inhibition of the thalamus thereby modulating motor activity. The direct pathway sends a "Go" signal to the thalamus, thereby weakening its tonic inhibition and allowing the execution of a motor plan (Centonze et al. 2001; Nishi, Snyder, & Greengard, 1997). Conversely, the indirect pathway sends a "No-Go" signal to the thalamus which strengthens tonic inhibition and suppresses motor activity (Centonze et al. 2001; Nishi et al. 1997).

These two pathways are distinguished by dopaminergic innervation, with the direct pathway being excited via dopamine D1 receptors, which respond to dopamine bursts, while the indirect pathway is tonically inhibited via D2 receptors, which respond to sudden dips in dopamine release (Waltz, Frank, Robinson, & Gold, 2007). The burst and dips of dopamine are known as phasic dopamine activity and indicate whether events are better or worse than expected (Schultz 1998, 2007). Dopamine bursts occur during positive outcomes when unexpected rewards are presented in the environment. They activate dopamine D1 receptors and strengthen the direct pathway so that the action is more likely to be repeated as we pursue further rewards, thereby facilitating 'Go' (approach) learning, and enhancing inhibition of the indirect pathway. Conversely, dips in dopamine occur when we experience punishment, this in turn activates dopamine D2 receptors and strengthens the indirect pathway by strengthening inhibition in the thalamus and reducing activity in the direct pathway, thereby supporting 'No-Go' learning in order to avoid repeating unrewarding choices (Frank 2005; O'Reilly and Frank 2006, Schultz 1998, 2007).

These Go and No-Go signals facilitate learning as they are susceptible to plasticity through experience to rewarding or aversive stimuli (Frank, Loughry, & O'Reilly, 2001; O'Reilly & Frank 2006). The mechanisms that allow us to learn through reinforcement are grounded in theories of psychophysiology and it has been hypothesized that they underlie the formation of our personalities (Gray, 1983). The BIS has a natural connection to No-Go learning in the indirect pathway. Aversive stimuli in the environment will activate the BIS as fear of punishing consequences will lead to an inhibitory No-Go signal being sent via the indirect pathway in the Basal Ganglia. Increased plasticity in this pathway may result in a person forming a disposition towards anxiety over time, making them more likely to be withdrawn and punishment oriented. Alternatively, the BAS has a natural connection to Go learning and the direct pathway. Appetitive reinforcers in the environment will activate the BAS as individuals search out rewarding consequences, thereby sending Go signals in the direct pathway of the Basal Ganglia. This increased plasticity in the direct pathway may result in an individual's proclivity towards impulsivity as they become more outgoing in their pursuit of rewards despite negative consequences.

1.3.2 Empirical evidence for the Reinforcement Sensitivity Theory.

1.3.2.1 Go /No-Go discrimination tasks. The Go/No-Go discrimination task assesses the ability of a participant to learn to respond to cues presented that have been previously paired with rewards and withhold responses to cues that have been paired with punishments (Yechiam et. al., 2006). Participants are typically presented with a choice of two cues and are given feedback upon choosing one of them. They learn by trial-and-error from this feedback to repeat correct choices and avoid repeating incorrect choices. This task is then paired with a psychometric measure of personality to test specific hypotheses.

Initially, the Eysenck Personality Inventory and the State-Trait Anxiety Inventory were used to assess the personality dimensions of Neuroticism/Extraversion and Anxiety but as research into Reinforcement Sensitivity Theory progressed new psychometric measures were developed. Torrubia & Tobena, (1984) and Muntaner & Torrubia (1985) developed the Susceptibility to Punishment scale and the Susceptibility to Reward scale to measure the anxiety and impulsivity dimensions of Gray's RST. Nearly a decade later Carver and White (1994) published an attempt to measure Gray's dimensions with their BIS/BAS questionnaire, which includes one scale for individual differences in BIS functioning, and three scales related to BAS functioning which load onto one BAS factor. Consequently, Torrubia et al. (2001) were able to develop the Sensitivity to Punishment and Sensitivity to Reward Questionnaire (SPSRQ).

Previous research has attempted to establish a link between Gray's theory and learning through punishment and reward with mixed results. A study using the Go / No-Go paradigm under conditions conducted by Zinbarg & Revelle, (1989), attempted to determine whether 'Go' cues would activate the BAS and 'No-Go' cues would activate the BIS, using the Eysenck Personality Inventory and the State-Trait Anxiety Inventory respectively, further they wanted to determine if BIS and BAS can be turned on and off based on the type of cue that was presented. They discovered that low anxious, high impulsive individuals learn about Go cues faster and form expectations of Go cues more rapidly, supporting the relationship between BAS and Go learning. Conversely, high anxiety, low impulsivity was found to facilitate No-Go learning in individuals, which lent support to a BIS / No-Go learning relationship. However, this study was unable to explain why high anxiety also facilitated Go learning in low impulsive individuals and hindered No-Go learning in highly impulsive individuals.

Additionally, Zinbarg & Mohlman, (1998) introduced both cash rewards as well as ego reinforcing incentives such as gains or losses in IQ points and asked participants to provide expectation ratings of success. They employed the Eysenck Personality Inventory to test for impulsivity and sociability, the State-Trait Anxiety Inventory to test for anxiety and Carver and White's scales to test BIS/BAS activation. Their results suggested that impulsivity is a complex construct in relation to reward system functioning with both functional and dysfunctional impulsivity playing a role in discrimination learning. Further, they discovered that Reward Responsiveness as measured by the BAS scale was more predictive than the impulsivity scale from Eysenck's Personality Inventory. Moreover, they were unable to conclusively explain the interactions between anxiety and impulsivity that were discovered in Zinbarg and Revelle's 1989 study. Though this study had expanded RST their findings were once again not conclusive, with some of their analysis being admittedly post hoc and highly speculative.

1.3.2.2 Probabilistic decision-making tasks. Subsequently, Caceres & San Martin (2017) have found that low cognitive impulsivity, the tendency to make rash choices without an appropriate evaluation of the alternatives, was associated with better performance on both minimizing losses and maximizing gains on a probabilistic decision-making task. Using the Cognitive Reflection Test (CRT), which is used to elicit an intuitive but incorrect response to measure cognitive impulsivity, they found that both loss and gain learning were positively associated with CRT scores. This indicates that low cognitive impulsivity is associated both with betting high when wins are likely and betting low when losses are imminent. The study gives two alternative explanations for these results, firstly, that individual differences in reward based or Go Learning are governed by dopaminergic signaling. Alternatively, impulsivity precedes choice behaviour, modulating the ability to learn the association between winning or losing probabilities. This implies impulsivity may be linked to both biological and metacognitive systems.

1.3.2.3 Other measures used to test Reinforcement Sensitivity Theory. Moreover, further research has been conducted into both learning accuracy and confidence in one's learning with a relationship between learning and overconfidence having been found. Krupić (2017) conducted a study to measure the effects of high BAS and low BIS on overconfidence, using the Reinforcement Sensitivity Questionnaire to measure BIS/BAS reactivity and the Sensitivity to Punishment and Sensitivity to Reward Questionnaire 20 to measure SR and SP, his research has found a significant positive relationship between BAS/SR and overconfidence and a significant negative relationship between BIS/SP and overconfidence. Overconfidence can be described as a measure that combines raw confidence and accuracy scores. However, rather than using a Go/No-Go paradigm he employed two behavioural tasks, one that required participants to hit targets from various distances by throwing discs and a learning labyrinth task that required participants to navigate a hand labyrinth blindfolded correctly at least twice. Therefore, he could not separate Go from No-Go learning ability, but could investigate relationship with confidence in one's overall learning.

These studies have shown that the behavioural systems that underly the personality dimensions of anxiety and impulsivity have greater complexity and only tentative links have been established between the BIS and BAS and learning from reward and punishment. Hence, there appears to be a gap in our understanding of these systems and confidence may be the missing factor that can be used to explain this lack of congruency in previous studies testing the Reinforcement Sensitivity Theory. With increasing evidence that elements of Gray's theory may be susceptible to not only biological explanations but metacognitive influences, further elucidation of these psychophysiological phenomena is warranted. Evidence showing that there is a relationship between overconfidence in learning and Reinforcement Sensitivity Theory suggests that the area of confidence judgements would be fertile ground to further explore this link.

1.4 Metacognitive Judgements

1.4.1 Confidence – What we know and what we do not know. The mechanisms we employ in order to make decisions are rooted in metacognitive abilities such as confidence judgements regarding the accuracy of our choices, so that we may reproduce behaviours that produce unexpected rewards and error monitoring to avoid repeating mistakes (Yeung & Summerfield, 2012).

The overall implication of the Reinforcement Sensitivity Theory is that behavior will, in mixed-incentive environments (i.e., most environments), reflect the combined influence of the BIS and BAS (Smillie, Pickering & Jackson, 2006). However, there is currently little consensus about how we might incorporate confidence into formal models of behaviour or explore its biological substrates (Yeung & Summerfield, 2012).

Lichtenstein and Fischhoff (1977) posed a pertinent question: “Do those who know more also know more about how much they know?”. Our metacognition, the awareness of our thought processes, plays a crucial role in our decision making, as we continuously make predictions and compare outcomes in order to maximise rewards and avoid punishments (Fiorillo, Tobler & Schultz, 2003). The accuracy with which we make these predictions can be characterised as confidence and it is believed to be a task specific metacognitive experience (Efklides 2011). Consequently, measures of confidence have been used successfully in studies of metacognition to assess peoples’ abilities to know what they know and what they do not know (Krebs &

Roebers, 2010). In particular, confidence can be used to assess metacognitive monitoring processes (Kleitman & Moscrop, 2010; Stankov, 2000), especially monitoring of learning from reinforcing or aversive stimuli.

1.4.2 Confidence as a trait. The accompanying sense of confidence that comes with even routine decisions is a universally subjective salient property of almost all our decisions (Yeung & Summerfield, 2012). Stankov (1999) places confidence in the "no-man's-land" between personality and cognitive abilities. His research shows that confidence has the properties of a trait, and that individuals tend to respond in a particular way when asked to indicate the level of certainty about the accuracy of one's answers across various situations (Stankov, 1999). Confidence may be the metacognitive process that helps us determine the likelihood of reward and punishment above and beyond our ability to learn from experience. Confidence scores form a factor that is distinct from accuracy measures, indicating that overall confidence is the essential monitoring component needed to trigger an action when making decisions.

The trait-like properties of confidence may be tied to mechanisms in the Basal Ganglia that affect the way we make decisions; however, this has not yet been explored as previous research has only measured overall learning, without differentiating between learning from reward vs learning from punishment (Krupić 2017).

1.4.3. Confidence – monitoring & control thresholds. The degree to which we are decisive, along with levels of recklessness or hesitancy in our decision making, can be predicted by the way we monitor confidence through control thresholds (Jackson, Kleitman, Stankov & Howie, 2017). Low control thresholds reduce the likelihood of missing opportunities for rewards, but at the risk of recklessly initiating poor actions, whereas high control thresholds reduce the risk of reckless errors, but at the cost of time delay and excessive hesitancy (Jackson et al., 2017). The level of hesitancy, illustrative of a high control threshold, may be associated with anxiety which is a feature of the BIS. Conversely, the level of recklessness, which is indicative of a low control threshold, may have links to impulsivity which is a product of the BAS. In turn, these systems may be controlled by the Basal Ganglia so our willingness to be decisive (and risk error) may be controlled by a single psychological process. This may explain the trait like properties of confidence. Individuals who set a high criterion relative to others in one context would also set a relatively high criterion in other contexts (Jackson et al., 2017). Consequently, they would be characterised as generally more decisive relative to others, that is, more likely to initiate actions faster and to be less hesitant, but also more reckless. This could be based on levels of dopaminergic innervation and rooted in the decision-making properties of dopamine bursts and dips in the Basal Ganglia, though formal models of the Basal Ganglia that explain both learning and confidence have not been proposed yet.

1.5 The Current Study.

This study aims to elucidate the relationship between personality, learning and confidence through a Go / No-Go task design to elicit reinforcement learning based on contingencies between one's choices and negative and positive feedback. Our manipulation of the reinforcement task will pair learning with a continuous analog scale in the test phase to measure overall confidence levels in one's learning from rewards and punishment, which has not been done before in the context of reinforcement learning.

As explained above, even though Reinforcement Sensitivity Theory predicts that SP is associated with No-Go learning and SR is associated with Go learning, the current literature reported mixed results. Consequently, we will test whether SP and SR can be predicted from reinforcement learning using a Go / No-Go discrimination task, additionally, we will also investigate whether we can better predict SP and SR from confidence levels on the Go / No-Go task. For this purpose, we have modified the traditional Go / No-Go task to include a measure of confidence in learning in addition to accuracy. We anticipate that stronger confidence ratings on Go learning trials will predict SR and stronger confidence on No-Go trials will predict SP. That is, since SR is a manifestation of the BAS, we hypothesize that there will be a relationship between SR and confidence on Go Learning trials. Conversely, since SP is a manifestation of the BIS, we hypothesize that there will be a relationship between SP and confidence on No-Go Learning trials. We anticipate that confidence will predict SR and SP to a greater extent than accuracy, since previous studies have found that Go and No-Go accuracy was not consistently associated with SR and SP.

Chapter 2: Method

2.1 Participants

N = 60 participants (33 Females) were recruited from the first-year Psychology participant pool at the University of Adelaide and the general population, with ages raging between 18 and 51 years (*M* = 24.1, *SD* = 7.7). Eligibility requirements included being aged 18 to 60 years, not suffering from drug or alcohol dependency, not smoking five or more cigarettes per day, not using medication that affects neurological function (e.g., antidepressants or sedatives), and not suffering from any uncorrected hearing or vision disorders. An *a priori* power analysis was conducted and determined that a minimum of 55 participants would be required to achieve a statistical power of 0.8 for this study.

2.2 Measures

2.2.1 Reinforcement learning task. A modified Go / No-Go paradigm was used to test reinforcement learning. The study employed a probabilistic learning task that consisted of a forced choice training phase followed by a subsequent testing phase (Frank et al., 2004). During the training phase the participants were presented with four stimulus pairs, where each stimulus was associated with a different probabilistic chance of receiving 'Correct' or 'Incorrect' feedback. These stimulus pairs (and their probabilities of reward) were termed A/B (85%/15%), C/D (85%/15%), E/F(70%/30%) and G/H(70%/30%). For stimulus pair AB, the choice of A was rewarded 85% of the time, while B was rewarded 15% of the time. Likewise for pair CD, C was rewarded 85% of the time and D was rewarded 15% of the time.The the EF and GH pairings were reinforced in a ratio of 70% for E and G and 30% for F and H.

Stimuli were displayed up to 4000 ms, during which the participant was required to choose one of the stimuli via a button press. Immediately after the response the feedback consisting of the words “Correct!” in blue text or “Incorrect” in red text, were presented on screen. If the participant did not respond in 4000ms the words “No Response Recorded” were shown. The feedback was received after 1000ms followed by an inter trial interval of 1500ms. Over the course of the training phase, a participant attempted to learn to choose the optimal stimulus, using only adaptive responding based on the feedback (Figure 3).

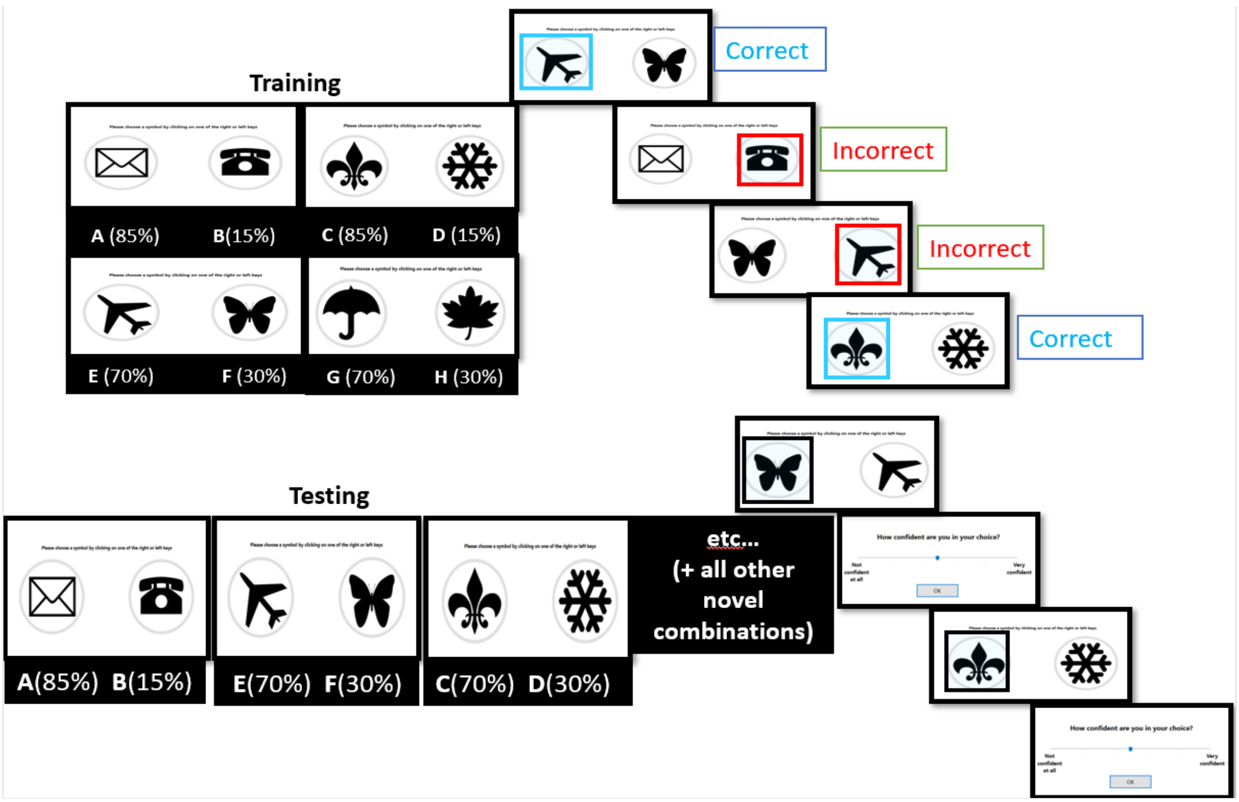

Figure 2. Go / No-Go learning task.

During training, each pair is presented separately. Participants have to select one of the two stimuli, slowly integrating ‘Correct’ and ‘Incorrect’ feedback (each stimulus has a unique probabilistic chance of being ‘Correct’) in order to maximise their accuracy. During the test phase, each stimulus is paired with all the other stimuli and participants must choose the best one, without the aid of feedback. After each trial they are asked how confident they are in their choice. Measures of reward and punishment learning are taken from the test phase, hypothesized to reflect the operations of a probabilistic integrative system during training.

We implemented a learning criterion whereby participants needed to reach 65% correct on AB and CD trials and 60% on EF and GH trials. The minimum and maximum amount of learning trials that participants could complete was 80 and 160, respectively.

To test whether the participants learned more from positive feedback (Go learning) or from negative feedback (No-Go learning), a testing phase followed the training phase. During the testing phase all possible stimulus pairs excluding the trained pairs and pairs of stimuli with the same reinforcement probability were presented twice each, for a total of 80 trials. Go Learning in this experiment is quantified as the probability of choosing the stimuli with the highest probability (A or C). Alternatively, No-Go learning is quantified as the probability of avoiding choosing the stimuli with the lowest reinforcement probability (B and D). The combinations are shown in Table 1.

Table 1

Contingencies shown during the learning phase and test pairs

Training	Test	
Contingencies	Choose A/C (Go)	Avoid B/D (No-Go)
A/B (85%/15%)	AD	BC
C/D (85%/15%)	AE	BE
E/F (70%/30%)	AF	BF
G/H (70%/30%)	AG	BG
	AH	BH
	CB	DA
	CE	DE
	CF	DF
	CG	DG
	CH	DH

2.2.2 Confidence measures. During the test phase a measure of confidence was introduced. On each test trial, after making a choice the participant was asked to rate their confidence in their choice on a sliding scale that ranged from 0-100. Confidence was measured using a visual analog scale with 0 indicating complete uncertainty and 100 being completely certain of accuracy (Figure 3).

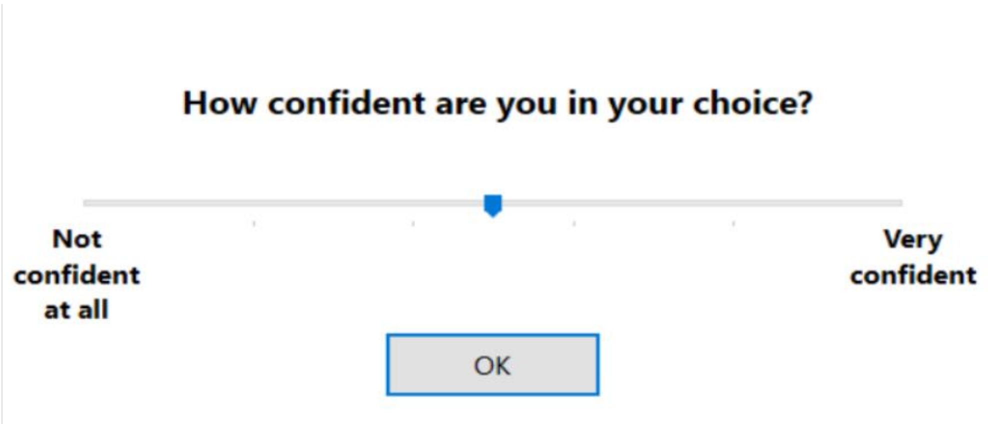

Figure 3. Confidence Scale.

2.2.3 Sensitivity to Punishment and Sensitivity to Reward Questionnaire – 20

The Sensitivity to Punishment and Sensitivity to Reward Questionnaire Short Version (SPSRQ-20) was used as the self-report measure (see Appendix B). This instrument uses a dichotomous yes/no response format, with the number of "yes" responses giving a final score (Cooper & Gomez, 2008). It is the combination of two subscales, each measured via 10 items. The first measures sensitivity to punishment (SP), and the second, sensitivity to reward (SR). The items are designed to avoid eliciting overlearned motivating situations in which most subjects would act in the same way. An example would be "would you go and get the money if you won a prize in a lottery?". Instead, items are designed to reflect situations in which there is a given probability of activating the BIS or the BAS and that may better reflect subtle individual differences, such as "Do you often buy lottery tickets?" (Torrubia et al., 2001). The short forms of the SP and SR scales that make up the SPSRQ-20 have Cronbach's α reliabilities of 0.85 and 0.75, respectively (Cooper & Gomez, 2008). They also have a test-retest reliability of .89 and .87, respectively, over a three-month period.

2.3. Procedure

Participants completed the entire experiment individually in a single session on an iMac desktop computer after being briefed on the contents and purpose of the experiment (see Appendix A), giving informed consent to participate and providing age and gender information. Identification numbers were used to ensure participant anonymity. Participants also completed other tests that are not analysed here as they were part of different projects. Sessions lasted between 1.5 and 2 hours. Each task was preceded by on-screen instructions about what the participant was required to do and how they ought to attempt to do it. The Go / No-Go probabilistic task was completed first followed by the SPSRQ-20. The computer screen informed participants when the experiment was complete and directed them to notify the researcher. This study was conducted under the approval of the Human Research Ethics Committee of the University of Adelaide (ethics approval number H-19/74).

Chapter 3: Results

3.1. Descriptive Statistics

Table 2 shows descriptive statistics in the form of means and standard deviations for the individual difference variables that were used in the primary analysis. Means for the Sensitivity to Reward and Punishment and Go and No-Go Learning Accuracy indicate that there were no significant gender differences in the sample (maximum t (56.09) = 0.196, $p = 0.91$). However, the Confidence Scores show a marginal, non-significant, gender difference (t(57.38) = 1.970, $p >$ 0.05) for confidence in Go learning, and (t (57.05) = 1.639, $p = 0.11$) for confidence in No-Go learning. Furthermore, participants were on average more sensitive to punishment than reward (t (59) = 4.223, p < 0.01). Further, participants appear to be more confident in Go Learning than in avoidance-based No-Go Learning (t (59) = 3.998, $p < 0.01$).

Table 2

Descriptive Statistics

Variable	Overall Mean (SD)	Mean (SD) for Women	Mean (SD) for Men
Age (yrs)	24.13 (7.72)	23.79 (8.03)	24.56 (7.45)
SR Scores	3.80 (2.18)	3.88 (2.37)	3.70 (1.96)
SP Scores	5.77 (2.95)	5.97 (3.02)	5.52 (2.91)
Go Learning	0.69 (0.20)	0.69 (0.18)	0.69 (0.21)
No-Go Learning	0.68 (0.18)	0.68 (0.18)	0.69 (0.18)
Go Confidence	62.30 (18.72)	58.14 (19.09)	67.40 (17.26)
No-Go Confidence	57.55 (17.82)	54.27 (18.16)	61.63 (16.84)

3.2. Correlations between Sensitivity Scores, Learning and Confidence

Correlations between Sensitivity Scores and Confidence Scores are shown in Table 3. SR had a strong positive correlation with Go Confidence ($r = 0.43$, $p < 0.001$) and a moderate positive correlation with No-Go Confidence ($r = 0.33$ $p = 0.011$). SP was not significantly correlated with any other measure besides age. No correlations were found between accuracy, and sensitivity scores. Likewise, there were no significant correlations between accuracy and confidence scores.

Table 3

Correlations of Sensitivity & Confidence Scores (N = 60)

	Age	SR	SP	Go Con	No-Go Con	Go L	No-Go L
Age	-						
SR	-0.310*	-					
SP	-0.416***	0.035	-				
Go Con	-0.325*	0.425***	0.058	-			
No-Go Con	-0.328*	0.326*	-0.002	0.874***	-		
Go L	-0.073	0.087	0.106	0.128	-0.049	-	
No-Go L	-0.094	-0.038	0.011	0.161	0.235	0.095	-

Note. ‘SR’ = Sensitivity to Reward. ‘SP’ = Sensitivity to Punishment. ‘Go Con” = Go Confidence Score. ‘No-Go Con’ = No-Go Confidence Score. ‘Go L’ = Go Learning Accuracy. ‘No-Go L’ = No-Go Learning Accuracy

* = $p < 0.05$. *** = $p < 0.001$

3.3. Multiple Linear Regression Models Explaining the Sensitivity Scores

We ran multiple linear regressions models to test if Go and No-Go accuracy would each explain variation in SP and SR scores while controlling for potential age and gender effects. Moreover, we tested whether the Go and No-Go confidence scores improved the amount of variance explained in the SP and SR scores. Finally, we used relative importance regression analysis to determine the relative amount of explained variance in SR and SP by each predictor (age, gender, Go Accuracy, No-Go Accuracy, Go Confidence and No-Go Confidence). This allowed us to determine the relative contribution of each variable to the overall R^2 in a multiple regression model (Groemping, 2006).

3.3.1 Sensitivity to reward regression models. Regression analyses were conducted to predict the SR scores. Regressors in the first model were age and gender and the model approached statistical significance, (F (2, 57) = 3.052, p = 0.055, R^2 = 0.10) The second model included Go accuracy and No-Go accuracy scores. This model explained a marginal, non-significant, increase in the proportion of variance in SR, (F (4, 55) = 1.636, p = 0.178, R^2 = 0.11). Thus, the overall model was not significant and the addition of the accuracy scores explained only an additional 1% of the variance; this increase in R^2 was not significant, ΔR^2 = .01, (F (2, 55) = 0.297, p = 0.745). This indicates that accuracy scores are not useful in predicting an individual's sensitivity to reward. The third model included the addition of Go confidence scores and No-Go confidence scores. This model explained a higher proportion of variance in sensitivity to reward, (F (6, 53) = 2.971, p = 0.014, R^2 = 0.25). Thus, the addition of confidence to the model explained an additional 15% of variance beyond that already explained by the second model and this increase was statistically significant, ΔR^2 = .15, (F (2, 53) = 5.1465, p < 0.01). In this model, only Go Confidence significantly predicted higher SR scores (see Table 4).

Table 4

Regression Models Predicting Sensitivity to Reward Scores

	R^2	*B*	*SE B*	*p*
Model 1	0.10			
Constant		5.733	1.265	< 0.001
Age		-0.087	0.035	0.017
Gender		0.108	0.547	0.844

Model 2	0.11			
Constant		5.821	1.965	0.005
Age		-0.088	0.036	0.019
Gender		0.109	0.554	0.844
Go Acc		0.775	1.381	0.577
No-Go Acc		-0.900	1.565	0.568
Model 3	0.25*			
Constant		2.140	2.263	0.349
Age		-0.053	0.036	0.150
Gender		0.580	0.538	0.286
Go Acc		0.030	1.387	0.983
No-Go Acc		-1.255	1.513	0.411
Go Conf		0.067	0.031	0.035
No-Go Conf		-0.023	0.033	0.487

Note. R^2 = explained variance. *B* = regression coefficient. *SE B* = standard error of regression coefficient. 'Go Acc' = Go Accuracy Score. "No-Go Acc' = No-Go Accuracy Score. 'Go Conf' = Go Confidence Score. 'No-Go Conf' = No-Go Confidence Score.

3.3.2 Sensitivity to punishment regression models. Regression analyses were conducted to predict sensitivity to punishment scores. Regressors in the first model were age and gender and the model reached statistical significance, (F (2, 57) = 6.08, p = 0.004, R^2 = 0.18) The second model additionally included Go accuracy and No-Go accuracy scores. This model was also significant, (F (4, 55) = 3.076, p = 0.023, R^2 = 0.18); however, the addition of the accuracy scores explained only an additional <1% of the variance and this increase was not significant,

$\Delta R^2 < .01$, (F (2, 55) = 0.236, p = 0.791). This indicates that accuracy scores are not useful in predicting an individual's sensitivity to punishment. The third model included the addition of Go confidence scores and No-Go confidence scores. The introduction of these additional variables did not improve model fit, (F (6, 53) = 2.268, p = 0.051, R^2 = 0.20) Thus, the addition of confidence to the model explained only an additional 2% beyond that already explained by the second model and this increase was not statistically significant, $\Delta R^2 = .02$, (F (2, 53) = 0.715, p = 0.494).

Table 5

Regression Models Predicting Sensitivity to Punishment Scores

	R^2	*B*	*SE B*	*p*
Model 1	0.18*			
Constant		9.066	1.640	< 0.001
Age		-0.158	0.046	0.001
Gender		0.330	0.709	0.643
Model 2	0.18*			
Constant		8.607	2.550	0.001
Age		-0.157	0.047	0.001
Gender		0.337	0.719	0.641
Go Acc		1.166	1.791	0.518
No-Go Acc		-0.558	2.030	0.784
Model 3	0.20*			
Constant		10.249	3.167	0.002
Age		-0.172	0.050	0.001

Gender	0.213	0.753	0.778
Go Acc	0.545	1.940	0.779
No-Go Acc	0.114	2.117	0.957
Go Conf	0.026	0.043	0.550
No-Go Conf	-0.048	0.046	0.305

Note. R^2 = explained variance. *B* = regression coefficient. *SE B* = standard error of regression coefficient. 'Go Acc' = Go Accuracy Score. "No-Go Acc' = No-Go Accuracy Score. 'Go Conf' = Go Confidence Score. 'No-Go Conf' = No-Go Confidence Score.

3.3.3 Relative importance regressions. These results are summarised in Figure. 4, which shows the results of relative importance regression for models that regressed each learning measure on age, gender, Go accuracy, No-Go Accuracy, Go Confidence and No-Go Confidence. This allowed us to determine the relative contribution of each variable to the overall R^2 in a multiple regression model (Groemping, 2006). As explained previously and clearly visible in Figure 4, Go confidence was the largest significant predictor of Sensitivity to Reward accounting for 47.5% of the explained variance, whereas Age was the only significant predictor of Sensitivity to Punishment, accounting for 86.1% of the explained variance (Figure. 4)

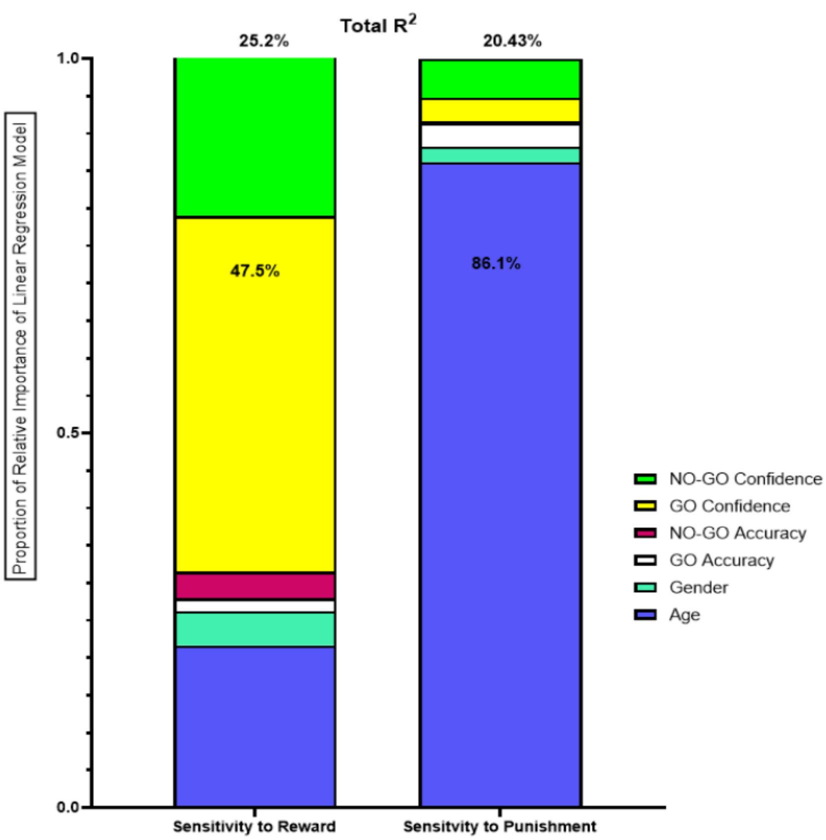

Figure 4. Relative Importance Regression Model

Chapter 4: Discussion

In the present study, we aimed to combine individual differences and experimental approaches to investigate the influence of confidence on sensitivities to punishment and reward. We examined whether confidence correlates with sensitivity to punishment or reward. Specifically, we aimed to confirm that confidence in learning and not accuracy in learning is the driving factor in predicting personality variables.

Our research did not find any correlation between reinforcement learning through reward or punishment and metacognitive judgements. However, our results revealed a significant relationship between confidence during Go learning conditions on SR. From this we can infer that confidence is distinct from learning. Furthermore, Stankov's hypothesis that confidence exists in 'no man's land' between ability and personality remains intact, however, our research shows that it is more closely related to personality than ability, at least when sensitivity to reward is a factor. Furthermore, as anticipated, accuracy scores were not a significant factor in predicting SR scores. Moreover, participant age was marginally predictive in the SR model. However, it was the primary and only predictor of the SP models as it had a highly significant negative correlation with SP score. Interestingly, none of the SP models showed any significant relationship to confidence measures or accuracy on Go or No-Go tasks.

Our study extended research in several respects. Firstly, we have established a link between measures of confidence and measures of personality in respect to a person's proclivity to learn from reward. Secondly, using linear regression models we were able to predict sensitivity scores using a Go / No-Go probabilistic reinforcement learning task.

4.1 Current Findings

4.1.1 Examining the relationship between confidence and sensitivity to reward. Our research can assist in the prediction of behaviour as reward-reactivity relates directly to motivation as rewarding events encourage approach behaviour. Moreover, this bi-directional relationship has implications for the field of personality research as people who are more susceptible to reward appear to have high levels of certainty in their metacognitive abilities.

We expected to see this relationship because confidence can be seen as the level of decisiveness that a person has in relation to making a choice. An individual's control threshold or their Point of Sufficient Certainty, has been operationalized as a measure of decisiveness, with high levels of decisiveness being reflective of more reckless behaviour and reduced hesitancy (Jackson et. al., 2017). This pattern of behaviour is synonymous with the personality dimension of impulsivity, which is considered to be a product of the BAS and is integrated in the dopaminergic systems of the Basal Ganglia.

With our research having established a relationship between SR and confidence we can infer that metacognitive judgements map onto the BAS through its associated personality dimension of impulsivity. From this we can attempt to predict how confidence will interact with the BAS in the space between Neuroticism and Extraversion (Figure 5.)

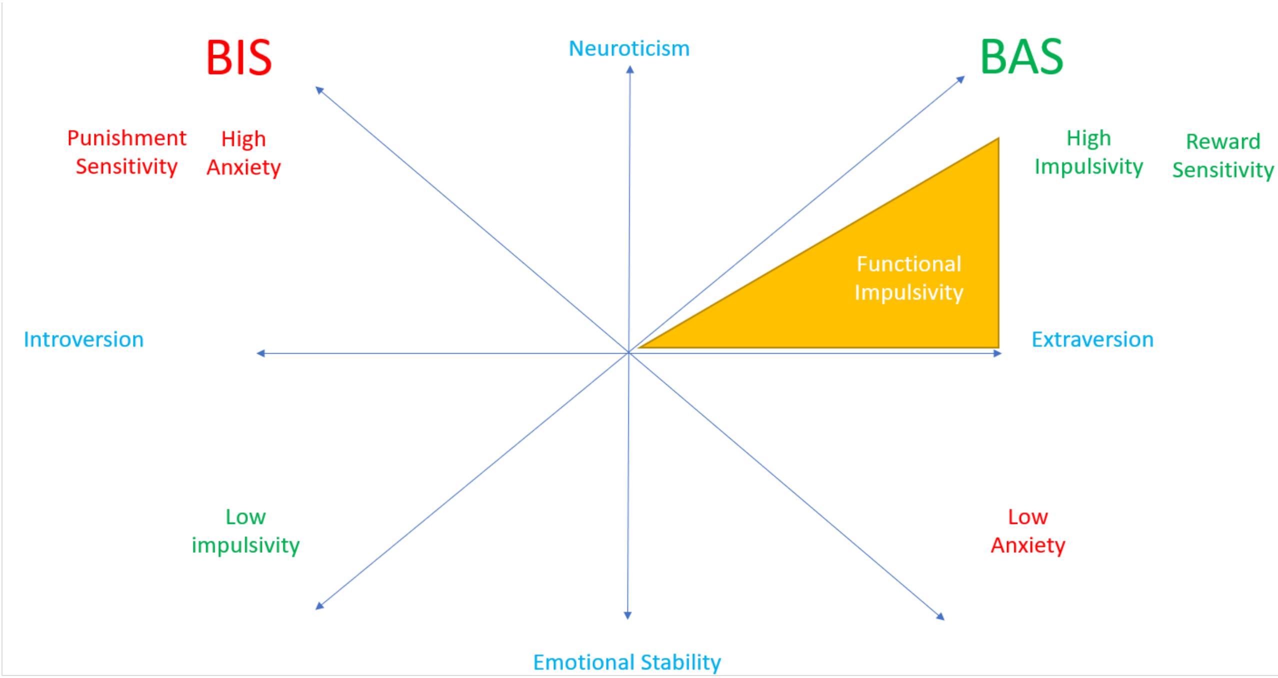

Figure 5. Functional Impulsivity.

4.1.1.1 Extraversion and delay discounting. Extraversion is strongly related to the sensitivity of the dopaminergic reward systems located in the Basal Ganglia (Depue & Collins, 1999), leading extraverts to experience most stimuli as more rewarding than introverts. Research suggests that extraverted individuals prefer immediate rather than delayed rewards (Ostaszewski, 1996). *Delay discounting* describes the extent to which the value of a reward decreases as the delay to obtaining that reward increases (Hirsh, Morisano & Peterson 2008). Consequently, high delay discounting would be exhibited by extraverted individuals who are exceedingly sensitive to reward as they would wish to be rewarded sooner. This would make them more impulsive, which would suggest BAS activation.

4.1.1.2 Delay discounting, passive-pvoidance & reflectivity. The need for immediate reward (high delay discounting) causes deficits in passive avoidance behaviours. Research has suggested the existence of two different mechanisms to explain passive avoidance deficits in extraverts. Firstly, BAS hyperactivity, which produces neurotic extraverts' behavioural disinhibition in mixed-incentive contexts, that is, it makes them more impulsive. Secondly, BIS hypoactivity, which causes stable extraverts' disinhibition in aversive contexts. Neurotic extraverts engage in impulsive behaviour because their tendency to respond in the hope of obtaining a reward is stronger than their tendency to inhibit a response, even though that response implies punishment (Segarra, Molto, & Torrubia, 2000). Both extraverts and introverts exhibit avoidance learning and reflectivity after punishment, however, extraverts reflect on punishment feedback for significantly less time (Patterson, Kosson & Newman, 1987). This lack of reflectivity makes them more susceptible to Go learning than No-Go learning. Patterson et.al. (1987), using a Go / No-go discrimination task, have demonstrated that extraverts' poorer learning of cues for punishment follows from their failure to pause after punishment and assess whether they should change their behaviour. Moreover, in the presence of reward incentives, extraverts are prone to maintain an approach response set making them more decisive, that is, more confident in their choices.

4.1.1.3 Functional impulsivity & reward reactivity. BAS-Impulsive individuals are thought to be more reactive to and more strongly motivated by positive incentive stimuli (Smillie & Jackson, 2006). Reward-reactivity is believed to be a combination of low behavioural inhibition and high behavioural activation (Corr, 2004).

Research by Dickman (1990) has posited that there is both dysfunctional impulsivity where people tend to “leap before they look” and functional impulsivity that is characterised by a tendency to “seize the moment”. This tendency to “seize the moment” is synonymous with the decisiveness criterion in confidence monitoring and is emblematic of the reward reactivity that is experienced by people that are high on SR.

Smillie & Jackson (2006) conducted a study, using a Go / No-Go task that employed a two-alternative, forced-choice task appropriate for Signal Detection Theory analysis, found that Functional Impulsivity and Appetitive Motivation, predicted the development of a response bias in favour of reward. Consequently, Functional impulsivity / reward-reactivity differ from other forms of Impulsivity in that it necessarily involves directed behaviour and the consideration of outcomes.

Dickman's (2000) suggestion that functional impulsives may be able to better attend to the decision-making properties of a situation hinges directly on the involvement of increased metacognitive functions. This additional processing may require confidence judgements and may represent an avenue for future research.

Although we have not assessed extraversion directly, Reinforcement Sensitivity Theory posits that Neurotic/Extraverts, i.e., impulsive individuals, will condition better to rewarding stimuli (Gray, 1981). Our results suggest that this type of impulsivity may be related to an individual's confidence in reward learning.

4.2 Failure to Predict Sensitivity to Punishment using Confidence

As we used different experimental paradigms than those employed in previous studies, we must be cautious in interpreting our results within the context of the most recent studies. Evidently, the current study's results do not correspond with those reported by Krupic et.al. (2017), who found significant negative correlations between SP and over-confidence scores. Rather, our results failed to find similar correlations, potentially this occurred because we used raw confidence scores rather than over-confidence scores which incorporate measures of accuracy. Our results may be due to the fact that our paradigm did not engage the punishment sensitive systems that Reinforcement Sensitivity Theory postulates, that is, our experimental paradigm did not activate either the BIS or Fight Flight Freeze System, which are primarily concerned with an individual's reaction to aversive stimuli. In the following, we distinguish between the BIS and FFFS in order to develop one potential explanation for this failure and suggest new avenues for future research.

4.2.1 The Fight Flight or Freeze System. The third conceptual system of Gray's Reinforcement Sensitivity Theory is the Flight, Fight or Freeze System (FFFS). It is primarily responsible for initiating avoidance and escape behaviours and mediating reactions to all aversive stimuli. The FFFS differs from the BIS in that it is not responsible for the resolution of goal directed conflict as it is governed by fear instead of anxiety (Corr, 2002).

4.2.1.1 Fear vs anxiety in relation to "defensive direction". Robert and Caroline Blanchard (1989) argued that the state of fear involved a set of behaviors evoked by a predator. Alternatively, the Blanchards linked the state of anxiety to a set of behaviors that involve the assessment of risk, they posited that immediacy or certainty brought on fear, whereas potentiality or uncertainty resulted in anxiety. Subsequently, research using anxiolytic drugs on behavior has shown that the key factor distinguishing fear and anxiety is 'defensive direction' (Corr & Perkins, 2006). Gray & McNaughton (2000) posit that fear operates when leaving a dangerous situation in the form of active avoidance, whereas anxiety activates when entering it or withholding entrance in the form of passive avoidance. As our experiment only measured passive avoidance through No-Go learning, we were unable to elicit the fear response needed to activate the FFFS. Both the FFFS and BIS relate to the trait of Neuroticism, moreover, recent research suggests that SP is governed more by fear than anxiety (Corr, 2004). The Go / No-Go task used in our experiment was not designed to elicit a fear response, it was only meant to elicit mild frustration in response to negative feedback.

In sum, when an individual enters an environment, he or she initially deals with any feelings of fear, if nothing triggers their FFFS then the complementary BIS system is activated, if nothing makes them anxious because there is no goal direct conflict then the BAS may become activated. Recent research suggests that the systems of Gray's theory work together, however, initial research into this area at the psychometric level proposed that the systems governed by reward and punishment were separable.

4.2.2 The Separable vs Joint Subsystems Hypotheses

4.2.1.1 The Separable Subsystems. In its initial conception the BAS and the BIS were described as reward and punishment mechanisms, both of which provide inputs to a decision mechanism where conflict between the two would be resolved according to whichever input was stronger (Gray, 1987, p. 180). Strong reinforcement of either mechanism would lead to partial or total inhibition of the other thereby creating a "winner-takes-all" system. This early research showed that the BIS and BAS were orthogonal to each other and were separable subsystems (Pickering & Gray, 1997). This hypothesis predicted that, on average, strong BAS (weak FFFS/BIS) individuals should be most reactive to reward, and weak BAS (strong FFFS/BIS) individuals should be most reactive to punishment (Corr, 2004). Specifically, it predicts that effects consistent with the separable subsystems hypothesis should be observed: (1) when hyper-active BAS/BIS individuals are tested; (2) when strong reward or punishing stimuli are used; and (3) in experimental situations that do not contain mixed reward and punishment cues (Corr, 2002). However, in human personality research, it may be unrealistic to assume that one reinforcement system dominates over the other (Corr, 2002).

4.2.1.2 The Joint Subsystems. Corr (2001) hypothesizes that in populations that do not display extreme BIS or BAS reactivity, or no strong appetitive or aversive stimuli are present, there will be a mutual interplay between the systems. Under normal environmental conditions in typical individuals there may be an additional metacognitive mechanism at play which may mediate or moderate the two biologically based systems, confidence may be part of that mechanism. Given this, our experiment was designed in a way that Joint Subsystems Hypothesis could be tested as we used a convenience sample of people in which we did not screen for extremes of personality, we used mild stimulation and our experiment combined mixed cues on every trial.

Given this, we contend our failure to predict SP from confidence scores from either Go or No-Go trials is the result of not being able to activate the underlying systems that react to punishment sensitivity. If participants were not sufficiently stimulated or motivated by fear or anxiety, then the only governing system that remains would be the BAS and it must have functioned as the default system as there was nothing sufficiently aversive in the environment. Consequently, future testing of confidence in relation to SP may include different experimental paradigms that elicit greater aversion in participants.

4.3 Improvements & Future directions

4.3.1 Changing the experiment to increase arousal and elicit BIS activation.

Despite observing a significant effect of confidence on SR we were unable to detect any such relationship with confidence and SP. We attribute this non-significant result to low arousal of the BIS/FFFS due to the nature of the Go / No-Go task. Given this, further research in which the we increase the level of arousal for the punishment condition thereby activating both the FFFS and BIS may constitute an important avenue for future research. Furthermore, the paradigm could be shifted from being orientated towards reward to one where passive-avoidance is the primary goal. In such an experiment, participants would need to learn to avoid aversive stimuli. Future experiments could introduce aversive unconditioned stimuli such as loud noise (75 decibels) to signal incorrect responses, thereby eliciting a fear response that may trigger the FFFS. It would be especially interesting to see what happens to confidence thresholds when there is more at stake than just negative feedback, and we would expect that SP would be correlated with confidence in No-Go avoidance learning.

Future research may also want to test differing type of rewards such as whether individuals change the certainty criterion based on whether they are rewarded by money of through ego enhancing stimuli like notional IQ points. Conversely, their confidence could be tested in the context of learning that certain cues signal losing money and notional IQ points. These manipulations would give experimenters the opportunity to study reward and punishment magnitude on learning and confidence.

Furthermore, the above tasks and manipulations could be correlated with other scales to more comprehensively assess the BIS and BAS. Using Carver and White's BIS/BAS scale or other measures of reward and punishment sensitivity could provide greater specificity regarding the influences of anxiety and impulsivity on confidence in Go learning. Our study only incorporated one measure for each sensitivity whereas other studies have used multiple measures to help triangulate personality and learning interactions.

Alternatively, other types of experimental paradigms that use signal detection theory could be employed to test monitoring and confidence thresholds. One way that this could be achieved would be to use a decision pattern analysis framework.

4.3.2 Decision Pattern Analysis. Decision Pattern Analysis is rooted in signal detection theory and built on the assumption that decision making is conducted to achieve our goals (Jackson & Kleitman, 2016). Future research could design a Go / No-go task using singular cue presentation and incorporating a decision to respond or not respond with associated gains or losses. This procedure will allow testing of the four decision categories (Hit, Miss, False Alarm and Correct Rejection). Subsequently, these decision categories could be used to generate a score for the five decision patterns (Figure 6).

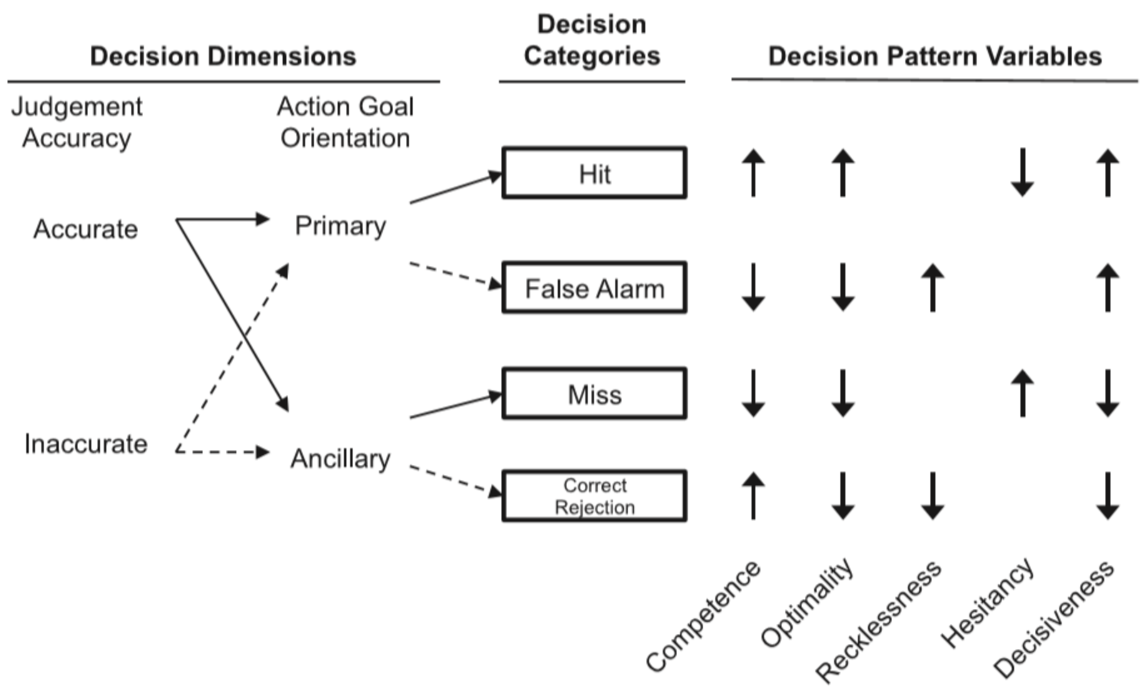

Figure 6. Decision Pattern Analysis. Solid black lines from judgement accuracy to decision category label represent decisions made following accurate judgements; Dashed lines represent decisions made following inaccurate judgements. Under the heading Decision Pattern Variables, upward pointing arrows represent decision categories that increase the score on that decision pattern; downward pointing arrows represent decision categories that decrease the decision pattern score.

Finally, those decision patterns could be compared to measures of SP/SR, BIS/BAS, Anxiety/Impulsivity, Extraversion/ Introversion to see if there is a relationship between personality traits like impulsivity and decision patterns like recklessness or decisiveness.

4.3.3 Age range. The current study focuses on a small sample that is not subject to cognitive impairment due to age. Testing an older population that is not homogenous, with varying levels of cognitive abilities, may increase our understanding of the processes involved. Similarly, people have been found to place less emphasis on monitoring output and control thresholds when making decisions as they get older (Pansky, Goldsmith, Koriat & Pearlman-Avnion, 2009). Furthermore, Crawford & Stankov (1996) have found that the elderly are unrealistically self-confident and consequently worse than young people in judging their own performance. Interestingly, older populations are more susceptible to degradation of their dopaminergic neurons and this degradation, that is reflected in the Basal Ganglia (Eppinger, Kray, Mock & Mecklinger, 2008), may be of interest to future research regarding confidence.

4.3.4 Basal Ganglia disorders. Future investigation of the links between impulsivity and confidence in populations that have disorders of the Basal Ganglia may provide a link to the neural substrates of confidence judgements. Disorders of the Basal Ganglia are characterized by abnormal levels of dopamine, with unmedicated Parkinson's patients being distinguished by lower than average levels of dopamine. Recently, research into the link between dopamine and impulsivity in Parkinson's patients has become an increasing area of interest as Parkinson's patients are characterized by abnormal levels of dopaminergic neurotransmission, when medicated they tend to develop impulsive disorders from the medications that are used to treat their symptoms (Voon et al. 2011). Alternatively, unmedicated patients of neurological disorders such as Tourette's Syndrome and Attention Deficit Hyperactivity Disorder (ADHD) typically have higher than average levels of dopamine.

These disorders create natural manipulations of the dopaminergic system and future research could benefit from testing the association between reinforcement learning and confidence in these populations to determine whether dopamine plays a role in confidence judgements. Previous research has mainly focused on accuracy as a measure of Go and No-Go learning, however, our research has shown that accuracy is not predictive of BAS reactivity and confidence is a better predictor.

There is growing evidence supporting that dopamine neurons code the level of uncertainty associated with a reward (Fiorillo, Tobler & Schultz, 2003). By varying the probability of reward from zero (where there is no chance of reward) to one (where there is a 100% chance of reward), reward becomes most uncertain when its probability is 50%, as it is unclear at this point whether or not a reward will occur. Dopamine neurons show a slowly increasing activation as the chance for reward increases from 0 to 50% and declines from 50 % to 100% (Fiorillo et al. 2003). This response has been hypothesized to constitute an explicit uncertainty signal (Schultz, 2010). Consequently, our reinforcement learning task with the added confidence scale manipulation could be tested in populations with naturally abnormal dopamine levels to ascertain whether similar effects can be observed; i.e., whether confidence judgments are affected by low and high dopamine levels. In demonstrating that confidence in Go learning is associated with sensitivity to reward our study has important implications for an updated model of the Basal Ganglia that incorporates confidence as it relates to certainty/uncertainty of decision-making.

Furthermore, dopamine processes have been implicated in a number of theoretical frameworks as a basis for Impulsivity, typically in relation to substance abuse (Peterson, Wolf, & White, 2003), disorders of disinhibition such as Attention Deficit/Hyperactivity Disorder (Davids, Zhang, Tarazi, & Baldessarini, 2003), and antisocial behavior (Goldman & Fishbein, 2000). An updated model of the Basal Ganglia would have profound implications for understanding diseases such as Parkinson's and Tourette's Syndrome where abnormal levels of dopamine or dopaminergic medication that are used to treat these disorders, can impair No-Go learning and lead to impulsivity disorders.

4.4 Practical Implications

From the psychometric point of view confidence ratings have been shown to be relatively insensitive to experimental manipulations and may be reliable measures under variable testing conditions (Stankov & Crawford, 1996). Furthermore, it is suggested that confidence ratings, like the accuracy scores, are stable and reliable measures of between-subjects variability (Stankov & Crawford, 1997). Additionally, confidence ratings are easy to collect in any testing situation and the cost in terms of time required is minimal (Stankov, Lee, Luo & Hogan 2012). Therefore, the addition of confidence ratings to existing tests of learning may yield an additional dimension that may help to screen for damage to neural networks that are affected by dopamine. Consequently, confidence ratings on a number of neurological tasks could be used to assess disturbances in decision-making.

Additionally, research into personality disorders that are characterized by deficits in passive avoidance learning such as psychopathy maybe effected by measuring metacognitive processes like confidence (Shane & Peterson, 2004). The extant literature regarding confidence argues that monitoring output and control thresholds are more important than cognitive abilities when modification of the decision-making process is of central importance as they may be more amenable to intervention than cognitive abilities, which are especially resistant to change (De Bruin & van Gog, 2012; Kleitman & Costa, 2014). Therefore, treatments maybe devised to help people with neurological and psychological disorders that are affected by learning and behavior by targeting confidence, which is more amenable to change than learning ability. Consequently, individuals have been shown to modulate their confidence levels under circumstances where they receive immediate feedback on the task that they are performing.

4.5 Conclusion

This study contributes to the current literature concerning the metacognitive judgements underpinning biological theories of personality. To our knowledge, our study is the first to integrate an individual differences perspective with an experimental approach to investigate the relationship between confidence and sensitivity to reward and punishment. Our study extends past research by investigating the relationship between personality and behaviour and the modulating influence of metacognition on those processes.

Our results provide support for the notion that confidence is found in the space between ability and personality with our research indicating that metacognitive processes may be in operation under conditions of functional impulsivity as we have discovered a relationship between confidence in Go learning and sensitivity to reward. Such findings should be considered in terms of practical implications for an updated version the Basal Ganglia model which in turn may help develop treatments and interventions for a host of neurological and psychological disorders. We found no significant results from our investigation in to the relationship between SP and confidence. Consequently, as our findings do not provide evidence for the role of confidence on SP, explicating the unique relationship between SP and confidence remains an important area of future study.

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Appendix A

Instructions for the Go / No-Go task

In this task you will be presented with different pairs of pictures, as in the example below. On every trial you will have to choose one of the pictures by pressing any of the keys on the left or the right side of the keyboard. For example, if you chose the flower symbol you would have to press any of the keys highlighted in blue below, and if you chose the fire symbol you would have to press any of the keys highlighted in red. You will only have 4 seconds to make a response, so don't waste too much time making a decision.

You will be informed whether your response was correct or incorrect. This feedback, however, will not always be consistent. For example, although the flower symbol below might be the better option, it will not always be followed by correct feedback. Your task is to discover which symbols are more likely to be correct and to maximise the number of correct choices.

To ensure that you respond as quickly as possible, keep the index of your left hand above one of the blue keys and the index of your right hand above one of the red keys.

Appendix B

SPSRQ-20 Questions

The SPSRQ–20

Answer each question by circling "Yes" or "No" after each one. There are no right or wrong answers, or trick questions. Work quickly and don't think too much about the exact meaning of the questions.

REMEMBER THAT YOU MUST ANSWER ALL THE QUESTIONS

4.-	Are you frequently encouraged to act by the possibility of being valued in your work, in your studies, with your friends or with your family?	Yes No
5.-	Are you often afraid of new or unexpected situations?	Yes No
9.-	Do you often renounce your rights when you know you can avoid a quarrel with a person or an organization?	Yes No
10.-	Do you often do things to be praised?	Yes No
12.-	Do you like being the centre of attention at a party or a social meeting?	Yes No
14.-	Do you spend a lot of your time on obtaining a good image?	Yes No
15.-	Are you easily discouraged in difficult situations?	Yes No
18.-	When you are in a group, do you try to make your opinions the most intelligent or the funniest?	Yes No
19.-	Whenever possible, do you avoid demonstrating your skills for fear of being embarrassed?	Yes No
21.-	When you are with a group, do you have difficulties selecting a good topic to talk about?	Yes No
24.-	Does the possibility of social advancement move you to action, even if this involves not playing fair?	Yes No
31.-	Are you often worried by things that you said or did?	Yes No
35.-	Do you generally try to avoid speaking in public?	Yes No
37.-	Do you, on a regular basis, think that you could do more things if it was not for your insecurity or fear?	Yes No
38.-	Do you sometimes do things for quick gains?	Yes No
39.-	Comparing yourself to people you know, are you afraid of many things?	Yes No
44.-	Do you like to put competitive ingredients in all of your activities?	Yes No
46.-	Would you like to be a socially powerful person?	Yes No
47.-	Do you often refrain from doing something because of your fear of being embarrassed?	Yes No
48.-	Do you like displaying your physical abilities even though this may involve danger?	Yes No

Note. SR_10 = 4, 10, 12, 14, 18, 24, 38, 44, 46, 48 (yes). SP_10 = 5, 9, 15, 19, 21, 31, 35, 37, 39, 47 (yes).